THE MODELING AND ANALYSIS OF AN ELASTIC MECHANISM WITH CLEARANCES

CHARLES WILLIAM GNILKA

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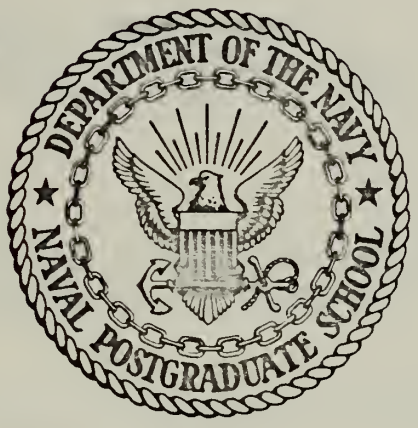

THESIS

THE MODELING AND ANALYSIS OF AN ELASTIC MECHANISM WITH CLEARANCES

by

Charles William Gnilka

Thesis Advisor: D. Salinas

December 1971

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The Modeling and Analysis of An Elastic Mechanism With Clearances

by

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Lieutenant, United States Navy
B.S., Villanova University, 1964

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ABSTRACT

The classical approach for the analysis of linkages has been to assume rigid elements during operation. As the operational speeds of mechanisms increase, this assumption creates larger errors in the analysis. Thus a better model of a machine that considers elastic deformations will aid in more efficient design as well as provide improved accuracy and performance.

This thesis presents a simulation for the dynamic response of an elastic link model with three clearances. The simulation has been developed for an automobile, cam actuated valve train. The computer program is coded in FORTRAN IV, for an IBM-360 computer and is included as a portion of this work. The capability to visually observe the dynamic action of the model is included by a graphic display routine. This routine is implemented in SDS FORTRAN IV for a SDS-9300 computer interfaced with an ADAGE Graphic Display Terminal, Model 10.

Sample problems for various cam speeds of interest are included utilizing graphs and photos from the graphic display.

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LIST OF SYMBOLS

A	Area
$[C]$	System damping matrix
c_{ij}	Element of damping matrix
E	Elastic modulus
F_i	Forces
$\{F^*\}$	Normalized force vector
g	Gravitational Constant
I	Moment of inertia
$[K]$	System stiffness matrix
k_{ij}	Element of stiffness matrix
L	Length
$[M]$	System mass matrix
M	Mass
m_{ij}	Elements of mass matrix
$\{p\}$	Force vector used in integration solution
q	System coordinate
t	Time
ΔT	Time increment used in integration solution
T_i	Period
u	Element coordinate
$\{\alpha\}$	Vector used in integration solution
$[\beta]$	Transformation matrix
ζ	Damping coefficient
	Cam angle of rotation

$\{\Phi\}$	Eigenvectors listed in columns, modal matrix
$\{\Psi\}$	Vector used in integration solution
ω_n, Ω	Natural frequency
$< >$	Row Vector

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I. INTRODUCTION

The classical approach to the dynamic analysis of linkages has been to assume that all menbers of the machine move without deformation during operation, i.e. that they move as rigid bodies. Based on this assumption, material choices and sizing to withstand stresses for the applied loads, the linkage deformations and the response motion have been severly idealized. Application of factors of safety have been necessary to account for this idealization. At lower operational speeds design criteria are met. However as the speeds increase the resulting large inertial forces and elastic deflections are more severe and thus the possibility of failure more acute. The design becomes invalid when the critical speed is reached where the machine either fails or where it no longer performs its intended task. Thus expensive and time consuming models must be built and tested, for elastic deformations over the range of operational speeds before the kinematic analysis can be fully accepted. The goal then is to obtain a more accurate dynamic model of a machine in order to better predict and understand its performance.

With the advent of the digital computer, more complex mathematical models of machine are being developed. Engineers are able to accomplish more refined designs with a higher degree of operational confidence, less of a factor of safety, better material choice, and fewer physical model experiments.

This work presents a simulation for the dynamic response of a planar elastic link mechanism, free to move in its rigid body motion

as well as its elastic motion. The structural elements deform elastically due to forces applied by neighboring elements, and due to inertial forces. This simulation has been developed for an automobile, cam actuated valve train, with three clearances. The clearances are considered to exist at the (1) cam-pushrod, (2) valve-valve seat, and (3) rocker arm-pushrod. To simplify the required derivations, the model is assumed to initially consist of straight members with constant circular cross-sectional bars. The assumption of constant circular cross-sectional bars is selected for ease in computing beam section properties. The use of straight links greatly simplifies the equations of elastic deformation.

An existing computer program written by Anderson and Winfrey (Ref. 2), was dependent on separately coded sections for each physical configurations of the two clearance model of a cam actuated valve train. As the number of system clearances are increased, the number of system configurations increase exponentially and separately coded program sections become infeasible.

The extent of this author's objectives and work on the existing program is to:

(1) Restructure and reprogram the simulation to provide for a generalized method for establishing the physical model configurations.

(2) Modify this program to allow for more than two clearances, i.e. add clearances internal to the system.

(3) Establish a method for the dynamic graphical display of the model showing the resulting elastic deformations of the model members at high operational speeds.

Objectives (1) and (2) have been accomplished using the IBM-360 computer for the simulation. Objective (3) has been accomplished with the aide of the ADAGE Graphics Terminal model 10 (AGT-10) interfaced with a Scientific Data System computer model 9300 (Photo 1.1). Data generated by the IBM computer is loaded into the SDS computer by means of punched cards or magnetic tape. This data is then manipulated into a form acceptable for display by the AGT-10.

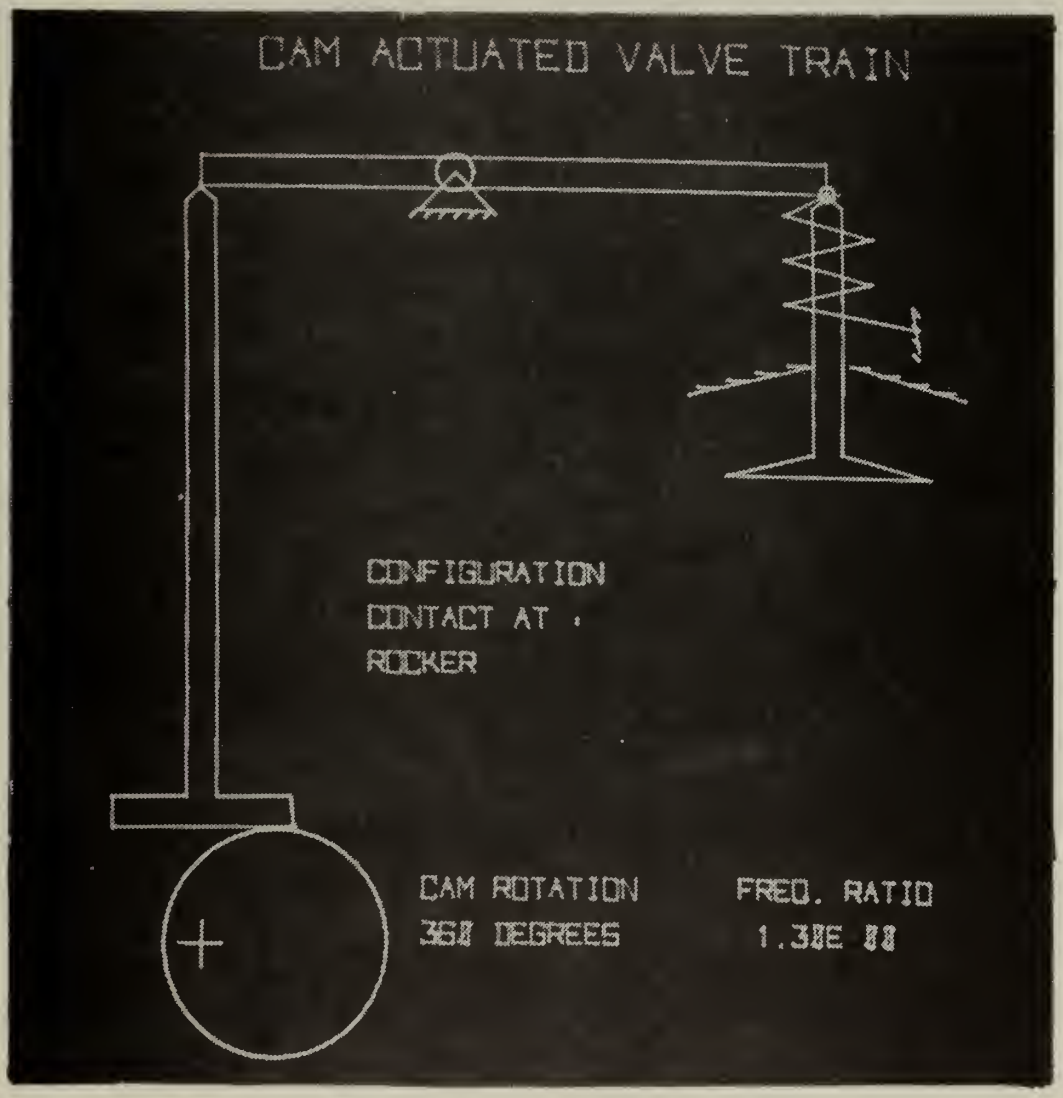


Photo 1.1 AGT DISPLAY

In the following chapters, the physical model, and the concepts and formulation for the corresponding mathematical model are described. The dynamic analysis and the elastic deformation computer programs are discussed and listed at the end of this work. Finally, several numerical examples are given with the model responses shown as AGT photographs and CALCOMP graphs.

In the following chapters, the physical model, and the concepts and formulation for the corresponding mathematical model are described. The dynamic analysis and the elastic deformation computer programs are discussed and listed at the end of this work. Finally, several numerical examples are given with the model responses shown as AGT photographs and CALCOMP graphs.

II. PHYSICAL MODEL

In this chapter the physical system, Figure 2.1, is idealized to enable formulation of a mathematical model whose analysis is tractable. The description covers the interaction between the system parameters and the physical contraints that limit the model's motion. The physical elements that comprise the system are listed and their functions explained. Additionally their physical properties, size and material content, are noted.

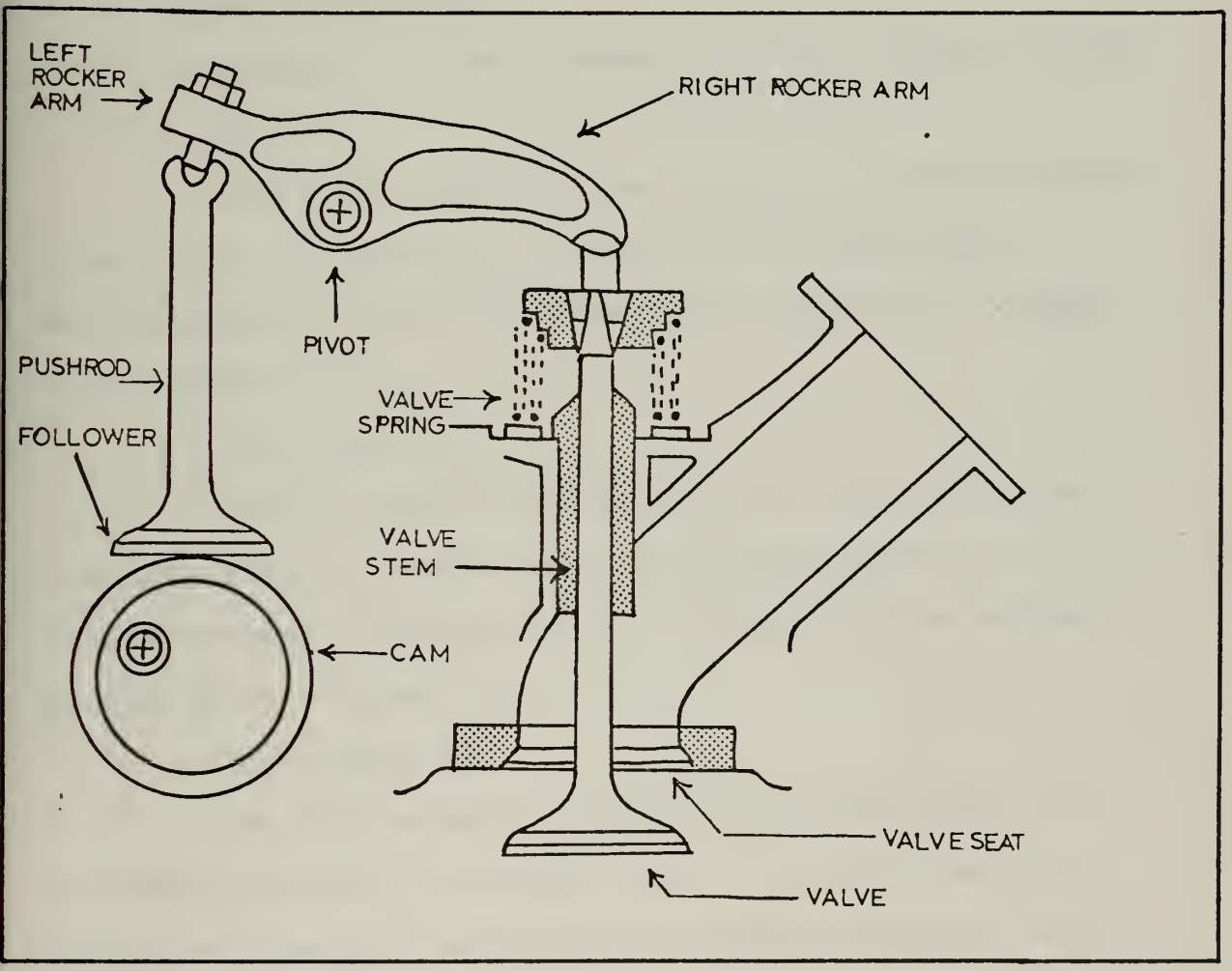


Figure 2.1 CAM ACTUATED VALVE TRAIN

A. GENERAL DESCRIPTION

In order to relate the formulation of this mathematical model to the real world, an automobile car engine valve train assembly is considered. However, any similar physical model might have been chosen. All members of the model are assumed to be manufactured from steel with an elastic modulus of 30×10^6 pounds per square inch and a specific weight of .283 pounds per cubic inch. Additionally longitudinal members are considered as rods with circular cross sections. The diameter and length of each bar are specified.

1. Elements of the Model

The elements of the valve assembly pictured in Figure 2.1 are:

a. Follower

This reciprocating flat faced follower is rigidly attached to the pushrod. The pushrod is considered as an elastic member. These members have harmonic displacement. The diameter is .3 inches; length 9 inches.

b. Left Rocker Arm

The left rocker arm is pinned to and rotates about the fixed pivot point at its right end. This element provides for an "internal" clearance between itself and the pushrod at its left end. The diameter is .6 inches; length 1 inch.

c. Right Rocker Arm

The right rocker arm is also pinned to and rotates about the fixed pivot point. At its right end it is pinned to the valve stem and valve spring. The diameter is .6 inches; length 1.5 inches.

d. Valve Spring

The free end of the valve spring is connected to the rocker arm and valve stem pin, the other end is rigidly fixed to ground. The spring is assumed to have a spring constant of 245 pounds per inch. The diameter is .07 inches; free length 36 inches.

e. Valve

This reciprocating valve is rigidly attached to the valve stem. The valve stem is assumed to be elastic. The upper end of the valve stem is connected to the common pin with the valve spring and right rocker arm. The diameter is .3 inches; length 3 inches.

To complete the model two additional elements are added external to the system. Both provide for the "external" clearances. They are:

f. Cam

The offset circular disk cam imparts sinosudial motion to the follower.

g. Valve Seat

This rigid seating surface for contact by the valve may be removed from the system when desired.

The rocker arm, although modeled as two elements, is considered to be one continuous member. Thus only rotation about the fixed pivot point is permitted.

2. Clearance Parameters

The clearance or interfereance at the valve seat may be eliminated by the introduction of a predetermined parameter. Due to the choice of the coordinate system, the parameter set less than the minimum value of the valve displacement has the effect of removing

the valve seat from the system. This provides for the flexibility to conduct studies of the valve motion unimpeded by the valve seat.

Additional flexibility of the model is provided by introduction of another clearance parameter. This parameter has the effect of eliminating the internal clearance between the pushrod and left rocker arm. Thus these two members can be pinned together when desired.

The circular disk cam rotates counterwise. This motion first lifts the follower by direct contact to its extreme position and next permits the follower to return to its initial position. The harmonic cycle is then repeated. For systems with cams of this type, the return motion of the follower must be accomplished by some force external to the cam. Therefore the valve spring is introduced to supply this force. For this work, simple harmonic motion is specified for the follower. The follower then oscillates about the midstroke position with an acceleration proportional to its distance from this position. The amplitude is half the stroke. The cam profile used to obtain the harmonic motion has been generated by the equation $.5 \sin(\omega t)$ inches, where ω is the cam speed in radians per second. Similar studies of various other cam profiles are discussed in Refs. 14-18.

B. ELEMENT COORDINATES

The model of the mechanism consists of two basic elements which account for all the relevant energy. The axial element, Figure 2.2 considers tension and compression forces. The bending element, Figure 2.3, considers only bending energy. The coordinates of the five

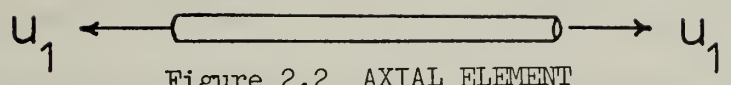


Figure 2.2 AXIAL ELEMENT

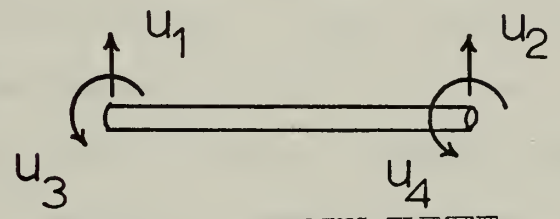


Figure 2.3 BENDING ELEMENT

elements of the system, i.e. pushrod, rocker arms, valve, and spring are chosen as indicated in Figure 2.4.

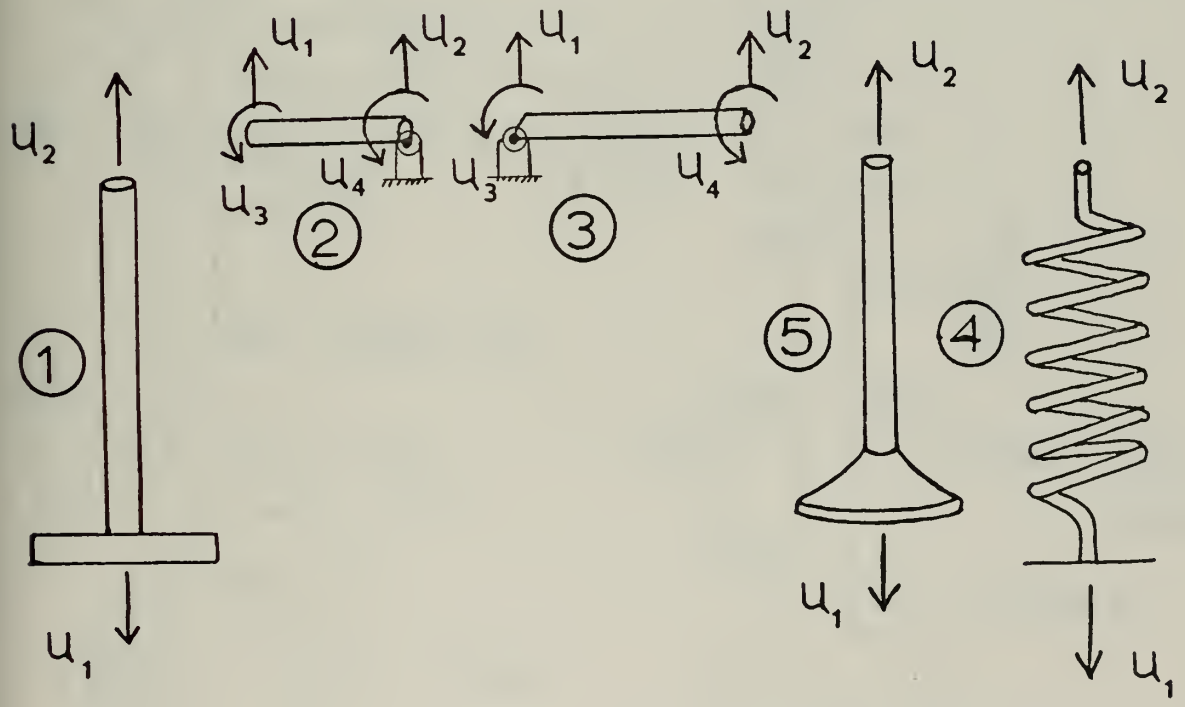


Figure 2.4 COMBINED ELEMENT COORDINATES

C. SYSTEM COORDINATES

Assuming small deformation theory, the linear model is composed of the above elements by superposition. The external members, the cam and valve seat, are also assigned coordinates for reference. As noted above, the pivot point and lower end of the spring are connected to ground and are therefore rigid. The systems coordinates {q} define motion. Since no motion is assumed for these two connections, no coordinates are necessary. Recalling that each member was assumed straight, the system coordinates will generally coincide with the element coordinates. The coordinate indices and their positive senses are shown in Figure 2.5.

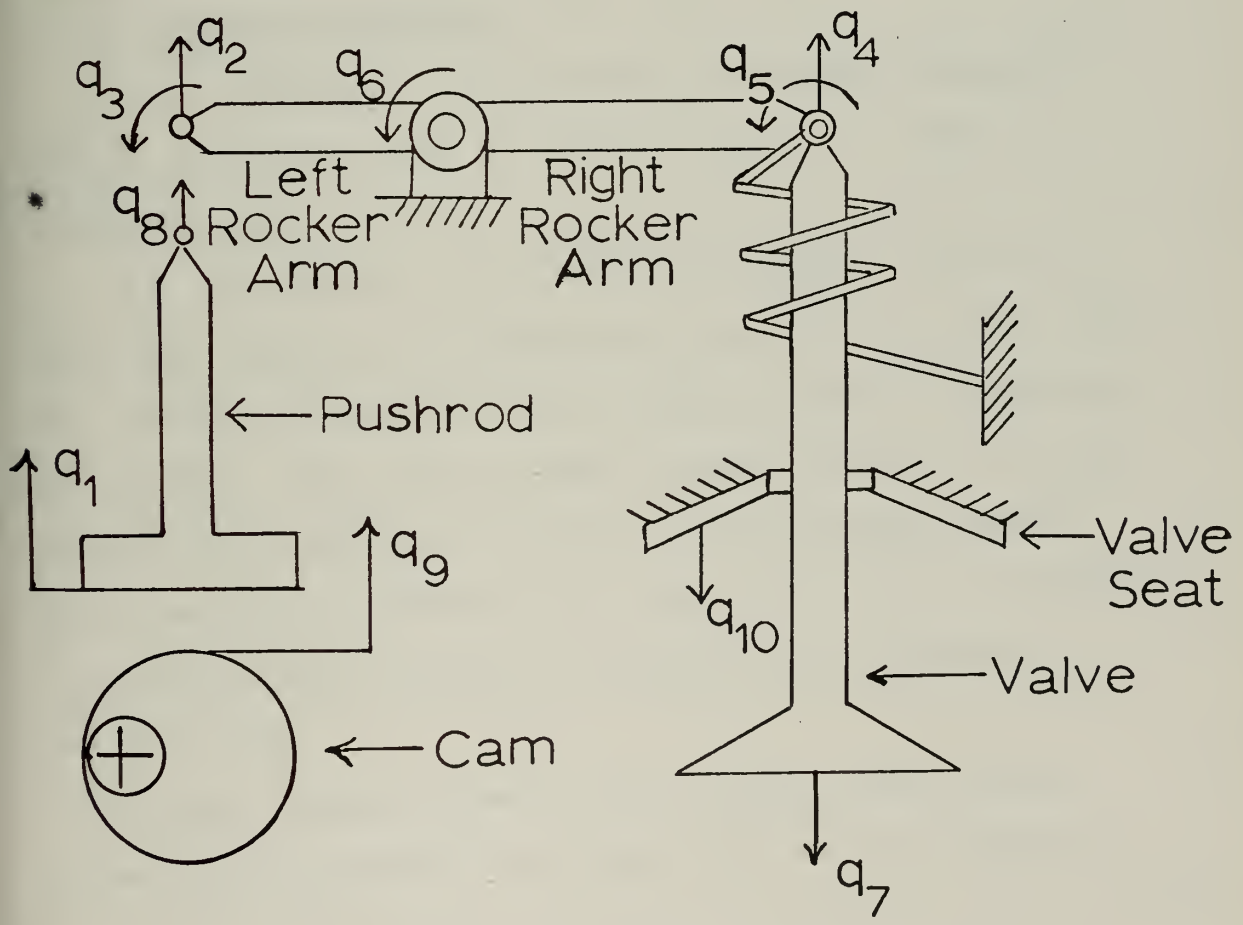


Figure 2.5 FULL SYSTEM COORDINATES

D. DEFINITIONS OF CONFIGURATIONS

The model shown in Figure 2.5 has two external clearances and one internal clearance. The term external refers to a displacement difference between a member of the system and an external member. Internal clearances are displacement differences between two internal members of the system. The clearances are:

1. External To The System

a. Clearance 1. The displacement difference between the cam, (coordinate nine), and the follower, (coordinate one).

b. Clearance 3. The displacement difference between the valve, (coordinate seven), and the valve seat, (coordinate ten).

2. Internal To The System

a. Clearance 2. The displacement difference between the pushrod, (coordinate eight) and left end of the left rocker arm, (coordinate two).

b. Clearance 4. The displacement difference between the valve stem, free end of the spring, and right end of the right rocker arm. The basic concept for the four clearance problem is presented in Appendix C. Since only the three clearance problem is considered for this work, clearance four is zero. Thus the members remain pinned and all move together at this connection. Only one coordinate is required to model the motion of the joint and is designated coordinate four.

Thus the external clearances define positions where external forces must be considered, i.e. forces associated with coordinate

one and coordinate seven. The internal clearances produce internal forces. These equal and opposite forces act upon the coordinate pair two and eight only when they are in contact.

The three clearances, where positive displacement differences between the coordinate pairs may exist, will be referred to as noted above, i.e. clearances 1, 2, and 3. Since clearance 4 will not be modeled, reference to this position will be referred to as coordinate four. Forces between clearances will be discussed in section 3.E.

E. SYSTEM CONFIGURATION

Depending upon the value of the force and displacement at these three clearances, the model can exist in one of eight possible configurations. If clearance 2 is considered pinned, the difference between coordinates two and eight is zero. The possible configurations is then reduced to four and is the study conducted by Anderson (Ref. 2).

The eight configurations are diagramed in Table 2.1 and 2.2. They are:

1. No contact at clearance 1, clearance 2, or clearance 3.
2. Contact at clearance 3; no contact at clearance 1, or clearance 2.
3. Contact at clearance 2; no contact at clearance 1, or clearance 3.
4. Contact at clearance 2, and clearance 3; no contact at clearance 1.
5. Contact at clearance 1; no contact at clearance 2, and clearance 3.

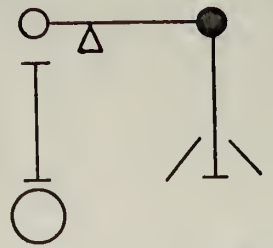
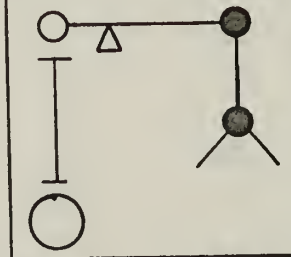
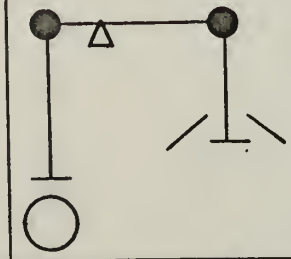
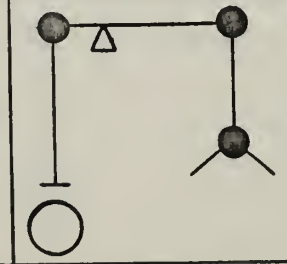
CONFIGURATION		CONTACT AT CLEARANCE	MONTORED VALUES		ASSUMED VALUES	
No.	Figure		Force	DISPL DIFF	Force	Displacements
I		NONE (NO CONTACT)	--	$q_1 - q_9$ $q_2 - q_8$ $q_7 - q_{10}$	$F_1=0$ $F_2=0$ $F_7=0$ $F_8=-F_2$	ALL VALUES CALCULATED
II		3 (VALVE SEAT)	F_7	$q_1 - q_9$ $q_2 - q_8$	$F_1=0$ $F_2=0$ $F_8=-F_2$	$\ddot{q}_7 = \ddot{q}_{10}$; $\dot{q}_7 = \dot{q}_{10}$; $q_7 = q_{10}$
III		2 (ROCKER)	F_2	$q_1 - q_9$	$F_1=0$	$\ddot{q}_2 = \ddot{q}_8$; $\dot{q}_2 = \dot{q}_8$; $q_2 = q_8$. $\therefore$ Seven Coordinate Reduced System
IV		2 and 3 (VALVE SEAT ROCKER)	F_2 F_7	$q_1 - q_9$	$F_1=0$ $F_8=-F_2$	$\ddot{q}_2 = \ddot{q}_8$; $\dot{q}_2 = \dot{q}_8$; $q_2 = q_8$ $\therefore$ Seven Coordinate Reduced System $\ddot{q}_7 = \ddot{q}_{10}$; $\dot{q}_7 = \dot{q}_{10}$; $q_7 = q_{10}$

TABLE 2.1 CONFIGURATION REFERENCE TABLE

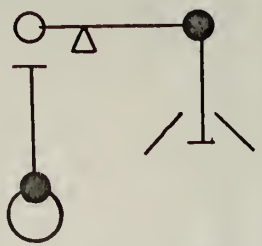
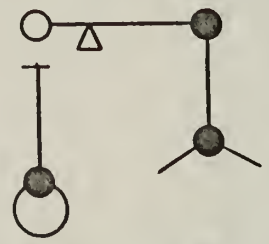
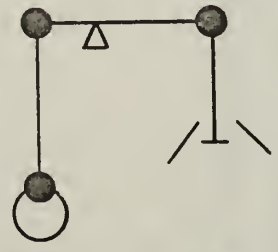
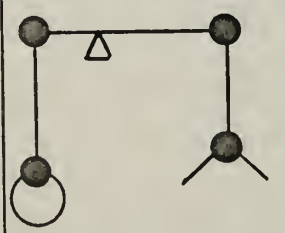
CONFIGURATION		CONTACT AT CLEARANCE	MONTORED VALUES		ASSUMED VALUES	
No.	Figure		Force	DISPL DIFF	Force	Displacements
V		1 (CAM)	F_1	$q_2 - q_8$ $q_7 - q_{10}$	$F_2=0$ $F_7=0$ $F_8=-F_2$	$\ddot{q}_1 = \ddot{q}_9$; $\dot{q}_1 = \dot{q}_9$; $q_1 = q_9$
VI		1 and 3 (CAM VALVE SEAT)	F_1 F_7	$q_2 - q_8$	$F_2=0$ $F_8=-F_2$	$\ddot{q}_1 = \ddot{q}_9$; $\dot{q}_1 = \dot{q}_9$; $q_1 = q_9$ $\ddot{q}_7 = \ddot{q}_{10}$; $\dot{q}_7 = \dot{q}_{10}$; $q_7 = q_{10}$
VII		1 and 2 (CAM ROCKER)	F_1 F_2	$q_7 - q_{10}$	$F_7=0$ $F_8=-F_2$	$\ddot{q}_2 = \ddot{q}_8$; $\dot{q}_2 = \dot{q}_8$; $q_2 = q_8$ $\therefore$ Seven Coordinate Reduced System $\ddot{q}_1 = \ddot{q}_9$; $\dot{q}_2 = \dot{q}_9$; $q_1 = q_9$
VIII		1, 2, and 3 (CAM ROCKER VALVE SEAT)	F_1 F_2 F_7	- - -	$F_8=-F_2$	$\ddot{q}_2 = \ddot{q}_8$; $\dot{q}_2 = \dot{q}_8$; $q_2 = q_8$ $\therefore$ Seven Coordinate Reduced System $\ddot{q}_1 = \ddot{q}_9$; $\dot{q}_1 = \dot{q}_9$; $q_1 = q_9$ $\ddot{q}_7 = \ddot{q}_{10}$; $\dot{q}_7 = \dot{q}_{10}$; $q_7 = q_{10}$

TABLE 2.2 CONFIGURATION REFERENCE TABLE (continued)

6. Contact at clearance 1, and clearance 3; no contact at clearance 2.

7. Contact at clearance 1, and clearance 2; no contact at clearance 3.

8. Contact at clearance 1, clearance 2, and clearance 3.

These eight configurations will be referred to as configurations I through VIII respectively.

The physical constraints of the system require that at any given instant of time, one and only one configuration will be satisfied. The forces and displacement differences at clearances 1, 2, and 3 are monitored to determine which configuration is valid for the calculated values. For example when the model is in a configuration that requires contact at a clearance and the calculated force at this clearance becomes zero (or negative), then contact is lost at that coordinate pair. Similarly, when the model is in a configuration that requires no contact at a clearance and the calculated displacement becomes zero (or negative), an interference exists and contact is regained at the coordinate.

The configuration and the values monitored for the appropriate coordinates are listed in Tables 2.1 and 2.2. Since this model always has contact at coordinate four contact at clearance 2 will be referred to as contact at the "rocker", (between left rocker arm and pushrod).

F. SHIFTING OF CONFIGURATIONS

As discussed above, the model shifts from one configuration to another, depending on first, the configuration the model is presently in; and second, the values of the monitored parameters. This shifting of configurations can be more easily understood by considering the flow diagram in Figure 2.6. The configuration schematic of the two clearance problem of Anderson (Ref. 2) appeared as a square, (face 3-4-8-7). As seen here the schematic of the three clearance problem becomes a cube. The solid lines and adjacent force parameter indicate a shift in the direction of the arrow caused by that particular force parameter. Similarly the dashed lines and adjacent coordinate parameters indicate a shift in the direction of the arrow caused by that particular negative displacement difference. Also indicated in the configuration flow diagram is an impact indicator. When a positive clearance becomes zero (or negative) a rapid change in the associated coordinate acceleration occurs which lends to high forces, i.e. impact. This is further discussed in section 3.F2. Impact is indicated by the rectangular boxes associated with the dashed shift lines. The figures within these boxes are the clearances at which the impact occurs.

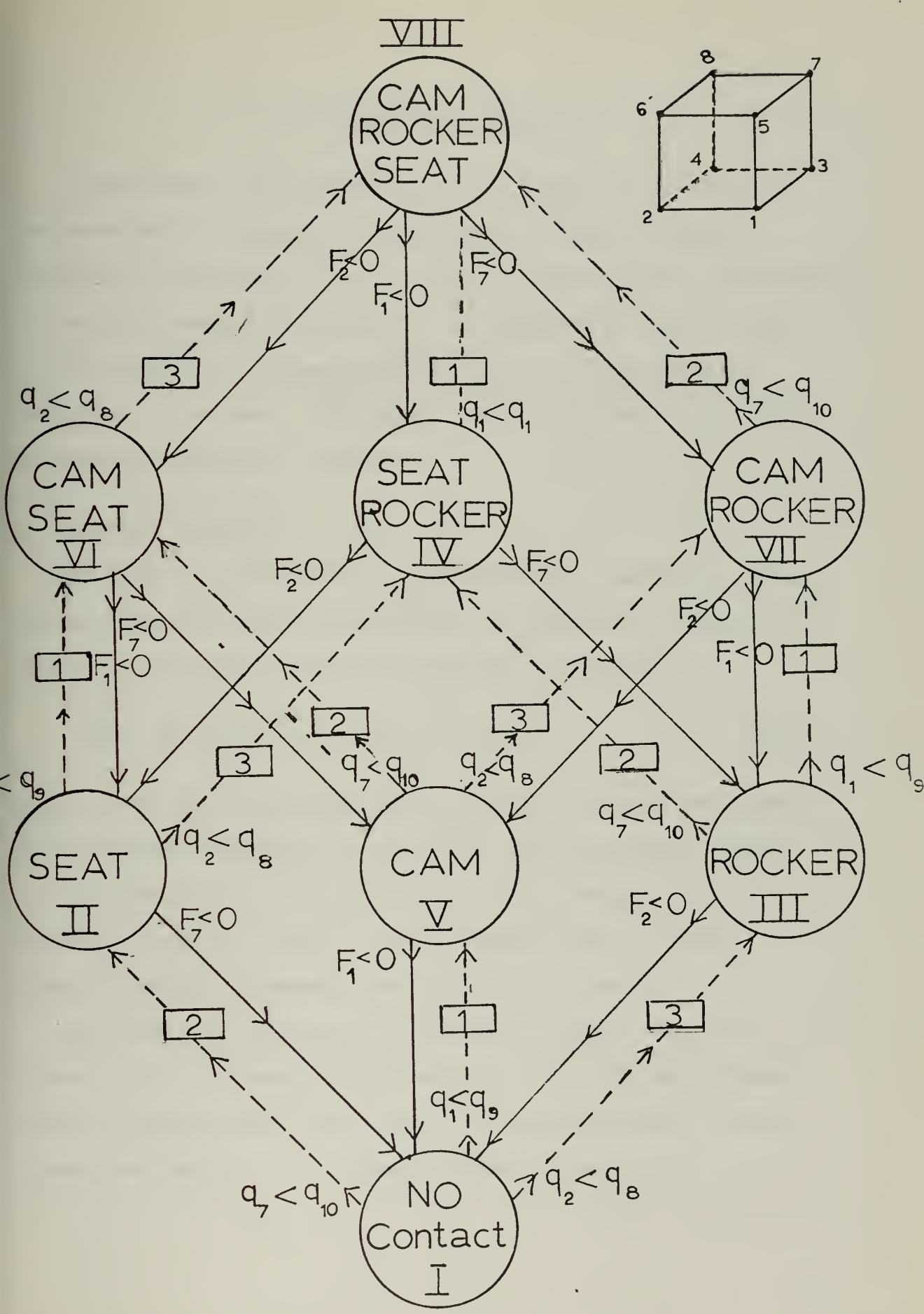


Figure 2.6 FOUR CLEARANCE SYSTEM CONFIGURATION SHIFTING DIAGRAM

III. MATHEMATICAL MODEL

In this chapter the equations of motion which apply to the model are presented and analyzed. The development of the system mass, and stiffness matrices; the two eigenvalue problems; and the formulation of the system damping are discussed. An algorithm to shift the model to the configuration corresponding to the values of the monitored parameters is presented. Finally the numerical methods by which the solutions are obtained is explained.

A. EQUATIONS OF MOTION

The model is considered to be a linear viscous damping spring-mass system, excited by time varying forces. The differential equations of motion can be written in terms of the system coordinates as

$$[M] \{\ddot{q}\} + [C] \{\dot{q}\} + [K] \{q\} = \{F\} \qquad (3.1)$$

where in the usual terminology, [M] represents the system mass matrix, [C] the system damping matrix, and [K] the system stiffness matrix.

The formulation of these matrices has been developed using Lagrange's equations, with the matrix elements based on finite element techniques, Rubenstein and Hurty (Refs. 8 and 9).

The elements of the model, as developed in section 2.B, have a discrete set of element coordinates (u_i = 1,2,....n) that represent the "n", rotational and translational element displacements. These element coordinates {u} are directly related to the system

coordinates {q} by

$$\{u\} = [\beta]\{q\} \tag{3.2}$$

The transformation matrix [β] is formed by applying the conditions of compatibility to the mechanism. For example, if element coordinate u_4 of element three is rotated by one unit, recalling that linear theory is assumed, it is seen that the relation is

$$(u_4)_3 = q_5 \ . \tag{3.3}$$

This scalar equation viewed as the matrix equation, (3.2), becomes

$$(u_4)_3 = \langle 0\ 0\ 0\ 0\ 0\ 1\ 0\ 0\ 0 \rangle \begin{Bmatrix} q_1 \\ q_2 \\ \cdot \\ \cdot \\ q_5 \\ \cdot \\ \cdot \\ q_8 \end{Bmatrix}$$

Thus the fifth row of the transformation matrix [β] has been obtained. By similar procedures, the entire transformation matrix for the eight coordinate system is developed. Therefore equation (3.2) can now be written as equation (3.4). Where the column matrix of the element coordinates, {u}, are partitioned by their appropriate elements, and the 14 x 8 transformation matrix, [β] is partitioned into sub-matrices corresponding to the respective elements. A more concise form may be written for equation (3.4) as seen in equation (3.5).

$$
\left\{
\begin{array}{ll}
\begin{Bmatrix} u_1 \\ u_2 \end{Bmatrix} & 1 \\
\begin{Bmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \end{Bmatrix} & 2 \\
\begin{Bmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \end{Bmatrix} & 3 \\
\begin{Bmatrix} u_1 \\ u_2 \end{Bmatrix} & 4 \\
\begin{Bmatrix} u_1 \\ u_2 \end{Bmatrix} & 5
\end{array}
\right\}
=
\left[
\begin{array}{cccccccc}
-1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
\hline
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
\hline
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
\hline
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
\hline
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0
\end{array}
\right]
\begin{Bmatrix} q_1 \\ q_2 \\ q_3 \\ q_4 \\ q_5 \\ q_6 \\ q_7 \\ q_8 \end{Bmatrix}
\qquad (3.4)
$$

$$
\begin{Bmatrix} \{u\}_1 \\ \{u\}_2 \\ \{u\}_3 \\ \{u\}_4 \\ \{u\}_5 \end{Bmatrix}
=
\begin{bmatrix} [\beta]_1 \\ [\beta]_2 \\ [\beta]_3 \\ [\beta]_4 \\ [\beta]_5 \end{bmatrix}
\{q\}
\qquad (3.5)
$$

B. MASS AND STIFFNESS MATRICES

The element mass $[M_e]$ and stiffness $[K_e]$ matrices are inherent characteristics of each element and can readily be formulated with finite element methods, (Refs. 1 and 8). The system mass [M] and stiffness [K] matrices can be formed with the aid of the transform matrix $[\beta]$ as:

$$[M] = \sum_{i=1}^{5} [\beta]_i^T [M_e]_i [\beta]_i \tag{3.6}$$

$$[K] = \sum_{i=1}^{5} [\beta]_i^T [K_e]_i [\beta]_i \tag{3.7}$$

where $[\beta]_i$ is the i^{th} element submatrix of $[\beta]$; $[K_e]_i$ is the i^{th} element stiffness matrix; and $[M_e]_i$ is the i^{th} element mass. The complete formulation is discussed in appendix A.

C. DAMPING MATRIX

The damping forces and hence system damping matrix is not as easily formulated since these values may depend upon the vibration of the system as well as elements exterior to it. To reduce the complexity of the solution of the differential equations of motion linear viscous damping is assumed.

The system damping is formulated by Hurty and Rubinstein, (Ref. 9) by: (1) solving the eigenvalue problem associated with the equations of motion of the system in undamped free vibrations,

for the modal matrix; (2) using this modal matrix to form the diagonalized system mass and stiffness matrices; (3) from these matrices forming the diagonalized system damping matrix; and (4) using this diagonalized damping matrix to solve for the system damping matrix.

The dynamic model consists of two eigenvalue problems. One eigenvalue problem is for the system of Figure 2.5. Here eight coordinates are required to solve the dynamic equations, since the pushrod and rocker arm are separated, coordinate two and coordinate eight have independent motion. The other eigenvalue problem is associated with the model in contact at clearance 2 and takes the form derived by Anderson (2). When the motion at coordinates two and eight are equal, the eight system equations must be reduced to a lower order system by removal of the redundant equation to facilitate a solution. Thus the system damping matrix, as well as the system mass and stiffness matrices, become order seven. This will be considered in section 3.E.

1. Uncoupling the Equations of Motion

When the differential equations of motion are derived from a set of convenient coordinates, the equations are normally coupled. If the system displacements $\{q\}$ are expressed in terms of the normal modes, the governing equations will uncouple. Thus from the equations of free undamped vibration

$$[M]\{\ddot{q}\} + [K]\{q\} = 0 \qquad (3.8)$$

the eigenvalue problem may be formulated as

$$\left([\omega^2][M] - [K]\right)\{q\} = \{0\} \quad . \tag{3.9}$$

The solution to this problem will yield the spectral matrix $[\Omega]$ and the modal matrix, $[\Phi]$.

$$[\Omega] = \begin{bmatrix} \omega^2 & & & 0 \\ & \omega_2^2 & & \\ & & \ddots & \\ 0 & & & \omega_n^2 \end{bmatrix} \tag{3.10}$$

$$[\Phi] = \left[\{\Phi\}_1, \{\Phi\}_2, \ldots \{\Phi\}_n\right] \tag{3.11}$$

The integer "n" is the number of degrees of freedom of the system i.e. n = 8 for the first eigenvalue problem discussed above and n = 7 for the second. The $[\omega_i]$ (i = 1, 2, . . . n) are the natural frequencies (or eigenvalues) of the system; and the $\{\Phi\}_i$ (i = 1, 2, ... n) are the column vectors of mode shapes (or eigenvalues) corresponding to the natural frequencies. Now the governing coupled equation of motion for undamped forced vibration,

$$[M]\{\ddot{q}\} + [K]\{q\} = \{F\} \tag{3.12}$$

may be decoupled by performing the coordinate transformation

$$\{q\} = [\Phi]\{\eta\}$$

The dynamic equation can now be written in terms of the modal coordinates $\{\eta\}$,

$$[m]\{\ddot{\eta}\} + [k]\{\eta\} = \{F^*\} \tag{3.13}$$

the uncoupled, diagonal mass $\lceil m \rfloor$ and stiffness $\lceil k \rfloor$ matrices, and the modal force vector $\{F^*\}$, Hurty and Rubinstein, (Ref. 9).

2. Relation of System Parameter To Modal Parameter

The diagonal matrices, $\lceil m \rfloor$, $\lceil c \rfloor$ and $\lceil k \rfloor$ are each related to their corresponding system matrices by transformation with the modal matrix.

$$\lceil m \rfloor = [\Phi]^T [M] [\Phi] \tag{3.14}$$

$$\lceil c \rfloor = [\Phi]^T [C] [\Phi] \tag{3.15}$$

$$\lceil k \rfloor = [\Phi]^T [K] [\Phi] \tag{3.16}$$

Additionally the modal acceleration $\{\ddot{\eta}\}$ and displacement $\{\eta\}$ are related to the system acceleration $\{\ddot{q}\}$ and displacement $\{q\}$ by the modal matrix.

$$\{\ddot{q}\} = [\Phi] \{\ddot{\eta}\} \tag{3.17}$$

$$\{q\} = [\Phi] \{\eta\} \tag{3.18}$$

3. Calculation of the System Damping

The system damping matrix may be obtained from equation (3.15) by matrix multiplication. Thus the diagonal elements of $\lceil c \rfloor$ must be calculated before the desired result, $[C]$, can be found. The governing equations are now uncoupled and the uncoupled mass $\lceil m \rfloor$ and stiffness $\lceil k \rfloor$ matrices are known. Thus the solution formulated for the simgle degree of freedom system may be applied to the n degree of freedom system.

Equations (3.19) through (3.21), from Thomson (Ref. 3), may be utilized to obtain the desired diagonal elements of the uncoupled damping matrix $[c]$. The natural frequency in radians per second of the undamped oscillation for a single degree freedom system is

$$\omega_n = \sqrt{k/m} \tag{3.19}$$

The damping factor (ζ), is defined as the ratio of the viscous damping (c) to the critical damping factor (c_c).

$$\zeta = c/c_c \tag{3.20}$$

The critical damping factor is also given by

$$c_c = 2\, m\, \omega_n = 2\sqrt{m\, k} \tag{3.21}$$

Upon substitution of equation (3.21) into equation (3.20), the viscous damping becomes

$$c = 2\zeta\sqrt{k\, m} \tag{3.22}$$

In terms of the uncoupled system, the value of the diagonal element of the natural frequencies, corresponding to equation (3.19), are

$$\begin{bmatrix} \omega_1 & & & 0 \\ & \omega_2 & & \\ & & \ddots & \\ 0 & & & \omega_n \end{bmatrix} = \begin{bmatrix} \frac{k_{11}}{m_{11}} & & & 0 \\ & \frac{k_{22}}{m_{22}} & & \\ & & \ddots & \\ 0 & & & \frac{k_{nn}}{m_{nn}} \end{bmatrix} \tag{3.23}$$

where the k's and m's are the diagonal elements from $[k]$ and $[m]$.

Similarly equation (3.22) can be written as

$$c_{ii} = 2\zeta_i \sqrt{k_i\, m_i} \quad (i = 1, 2, \ldots n) \qquad (3.24)$$

and thus the diagonal values of the uncoupled damping matrix $\left[\searrow c \swarrow\right]$ are obtained.

An arbitrary choice of values for the damping factor vector $\{\zeta\}$ was considered on the basis of the natural frequencies. The damping factor, (ζ_i), corresponding to the fundamental frequency is set equal to $\frac{1}{2}$. The remaining elements of $\{\zeta\}$ are set to equal 1/10.

Having established $\left[\searrow c \swarrow\right]$, the damping matrix [C] may be formed from equation (3.15) by matrix multiplication on the left by $\left[\Phi^T\right]^{-1}$ and on the right by $[\Phi]^{-1}$ as

$$\left[\Phi^T\right]^{-1} \left[\searrow c \swarrow\right] \left[\Phi\right]^{-1} = \left[\Phi^T\right]^{-1} \left[\Phi\right]^T \left[C\right] \left[\Phi\right] \left[\Phi\right]^{-1} \qquad (3.25)$$

This gives the desired result

$$\left[C\right] = \left[\Phi^T\right]^{-1} \left[\searrow c \swarrow\right] \left[\Phi\right]^{-1} \qquad (3.26)$$

D. CONFIGURATION SHIFTING ALGORITHM

For the two clearance problem four configurations were established. This work provided for three clearances having eight possible model configurations. For the addition of the clearance at coordinate four, a total of 4 clearances, there would exist sixteen possible system configurations. Thus the number of possible configurations

of an "n" clearance system would be 2^n. A generalized method of selecting the proper configuration on the basis of the monitored parameters is therefore necessary.

The physical model will shift configurations only on the basis of two general parameters, displacement difference and force. Thus a binary number system facilitates the problem of "computer bookkeeping". This is accomplished by assigning the value one to a clearance that is in contact and a zero to a clearance not in contact. For the unique choice of configurations established in chapter 2, Figures 2.4 and 2.5, the configuration matrix is developed as shown in Figure 3.1.

		CLEARANCES		
		#1	#2	#3
CONFIGURATION	1	0	0	0
	2	0	0	1
	3	0	1	0
	4	0	1	1
	5	1	0	0
	6	1	0	1
	7	1	1	0
	8	1	1	1

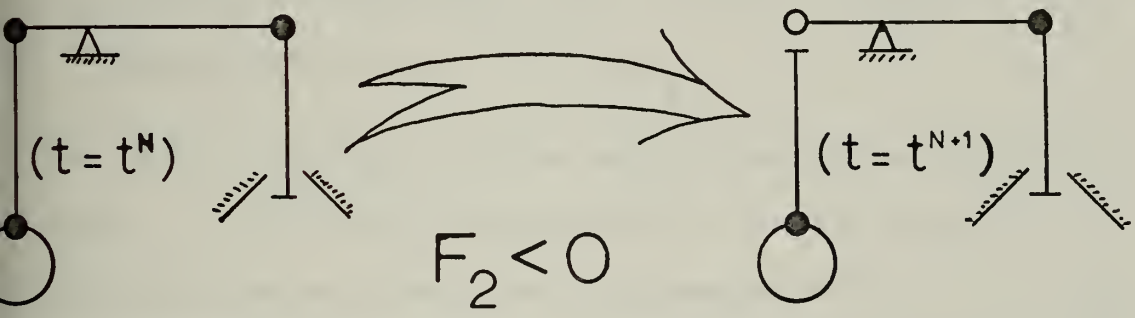
Figure 3.1 Configuration Matrix

The columns of this matrix are associated with clearances 1, 2, and 3 as indicated. The rows are associated with the configuration number that the physical system has taken. Thus to retrieve the correct configuration the entire row is taken as a binary number and converted to a decimal number. Since it is not

convenient to have a configuration numbered zero, a one was arbitrarily added.

For example, when no contact exists at all clearances, the binary number representing this configuration is 0 0 0. This binary number converts to decimal as 0 . Upon adding the above mentioned value one, the decimal value becomes 1, which is the first row of the matrix and hence configuration I.

The binary number 1 1 1 represents contact at all clearances and converts to decimal 7. Adding one yields the value 8, the 8^{th} row of the configuration matrix and hence configuration VIII.



CONFIGURATION VII CONFIGURATION V

Step 1: VII → 1 1 0

Step 2: 1 ⊕ 1 = 1 0

Step 3: 1 0 0

Step 4: 1 0 0 → V

⊕ indicates binary addition

Figure 3.2 Shifting Example No. 1

The manner in which the program determines which configuration the model has shifted into is of primary concern. The developed algorthm is an extension of the above concepts, and best described

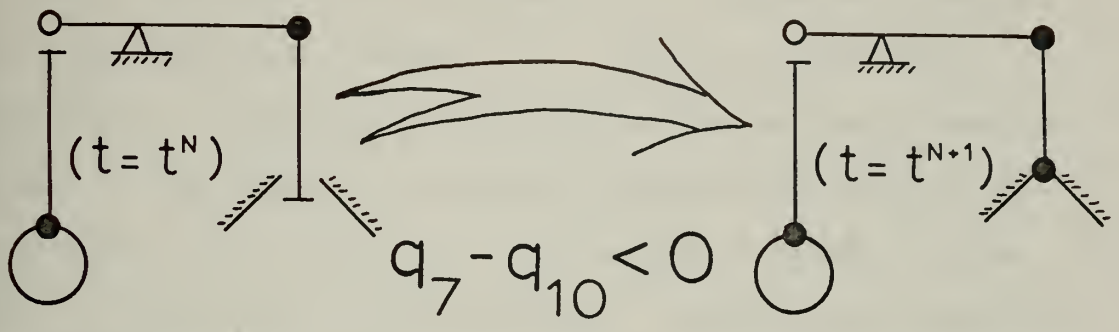
by way of examples. For the dynamic behavior pictured in Figure 3.2, the sequence of events is:

(1) The model is in one of the eight given configurations, i.e. VII at time t^n.

(2) The program calculates the required parameters for the next time step, t^{n+1}. Among these parameters are the monitored values. In this example the monitored value F_2 has changed during the time step, i.e. F_2 has gone from $F_2 > 0$ to $F_2 < 0$.

(3) The negative force at coordinate two indicates the loss of contact at clearance 2. Thus the model now shifts to configuration V for time t^{n+1}, (Figure 2.6).

The four step shifting algorithm accomplishes this as outlined in Figure 3.2. The binary representation for configuration VII is retrieved from row seven in the configuration matrix, 1 1 0. Next the column of the binary number corresponding to the clearance that has been altered is removed. In this example, the element being the second digit of the binary number which correspond to the clearance 2 column. A one is then added, by binary addition, to this element. Carries are disregarded. The new second digit 0 is placed into the binary number. Finally the new resulting binary number is converted to decimal and yields the new configuration number, V.



CONFIGURATION V CONFIGURATION VI

Step 1: V ⟶ 1 0 0

Step 2: 0 ⊕ 1 = 1

Step 3: 1 0 1

Step 4: 1 0 1 ⟶ VI

⊕ indicates binary addition

Figure 3.3 Shifting Example No. 2

The second example for the shifting algorithm is shown in Figure 3.3. The sequence of events for the dynamic behavior is:

(1) The model is in configuration V at time t^n.

(2) The program calculates the required parameters at the next time step t^{n+1}. In this example, the monitored displacement difference value $q_7 - q_{10}$ has changed from $q_7 - q_{10} > 0$ to $q_7 - q_{10} < 0$.

(3) The negative displacement difference at the coordinate pair 7 - 10 indicates that contact is established at clearance 3. Thus the model now shifts to configuration VI for time t^{n+1}.

The shifting algorithm accomplishes this as outlined in Figure 3.3. The binary representation for configuration V is retrieved from row five in the configuration matrix, 1 0 0. Next the column of the binary number corresponding to the clearance that has been altered is removed. In this example, the element being the third digit of the binary number which corresponds to the clearance 3 column. The new digit, 1 is placed into the binary number. Finally the new resulting binary number is converted to decimal and yields the new configuration number, VI.

E. METHOD OF CALCULATIONS

Newmark's β parameter method, (Ref. 4), forms the basis for the calculations. This one step numerical intergration procedure assumes the accelerations of the system coordinates are a linear function of time. Errors introduced by this assumption are given by $\omega_n \Delta T/6$, where ω_n is the highest natural frequency of interest. For small time steps this error is negligible. In this study the time step is taken as

$$\Delta T = 1 \times 10^{-6} \text{ seconds} \qquad (3.27)$$

It will be shown, by example that the solution to the equations of motion takes a convenient form. Precalculated matrix expressions may generally be used, resulting in large savings of computer execution time. A basic familiarity with the formulation of Newmark's method (Appendix B) will prove helpful and aid in the understanding of the following discussion.

The development of the problem calculations will assume the model has been operating in configuration VI, contact at the cam and valve seat. The procedures are identical by extension, to the remaining seven configurations. Thus the problem unknown quantities have been calculated for time $t = t^n$. The object is to solve the governing equations for the next time increment $t = t^{n+1}$.

1. Solution to the Governing Equations

The full system matrices [M], [C], and [K] have been developed in sections 3.B and 3.C. The governing equations of motion are expressed as the matrix equation 3.1 in section 3.A. Written in concise form the governing equations for the eight system coordinates are

$$\left[m_{ij}\right]\{\ddot{q}_i\}^{n+1} + \left[c_{ij}\right]\{\dot{q}_i\}^{n+1} + \left[k_{ij}\right]\{q_i\}^{n+1} = \{F_i\}^{n+1}$$

$$(i = 1,2,\ldots 8;\ j = 1,2,\ldots 8) \qquad (3.28)$$

Exterior forces, F_1^{n+1} and F_7^{n+1}, are unknown. The remaining applied forces F_i^{n+1} $(i = 2,3,..6,8)$ are equal to zero. Since the cam and follower are in contact, the known cam values at reference coordinate nine, $\ddot{q}_9^{n+1}$, $\dot{q}_9^{n+1}$, and q_9^{n+1} are equal to the corresponding follower values at system coordinate one, $\ddot{q}_1^{n+1}$, $\dot{q}_1^{n+1}$, and q_1^{n+1}. Similiarly, the known values for the stationary valve seat at reference coordinate ten, $\ddot{q}_{10}^{n+1}$, $\dot{q}_{10}^{n+1}$ and q_{10}^{n+1} are set equal to those corresponding values for the valve at system coordinate seven, $\ddot{q}_7^{n+1}$, $\dot{q}_7^{n+1}$, and q_7^{n+1}. Displacements

q_i^{n+1} (i = 2, 3, ... 6, 8) are unknown. Expanding and partitioning equations 3.28 to take advantage of the known values yields

$$\begin{bmatrix} m_{11} & m_{12} & \cdots & m_{16} & m_{17} & m_{18} \\ m_{21} & m_{22} & \cdots & m_{26} & m_{27} & m_{28} \\ \vdots & & & & & \\ m_{61} & m_{62} & \cdots & m_{66} & m_{67} & m_{68} \\ m_{71} & m_{72} & \cdots & m_{76} & m_{77} & m_{78} \\ m_{81} & m_{82} & \cdots & m_{86} & m_{87} & m_{88} \end{bmatrix} \begin{Bmatrix} \ddot{q}_1 \\ \ddot{q}_2 \\ \vdots \\ \ddot{q}_6 \\ \ddot{q}_7 \\ \ddot{q}_8 \end{Bmatrix}^{n+1} + \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{16} & c_{17} & c_{18} \\ c_{21} & c_{22} & \cdots & c_{26} & c_{27} & c_{28} \\ \vdots & & & & & \\ c_{61} & c_{62} & \cdots & c_{66} & c_{67} & c_{68} \\ c_{71} & c_{72} & \cdots & c_{76} & c_{77} & c_{78} \\ c_{81} & c_{82} & \cdots & c_{86} & c_{87} & c_{88} \end{bmatrix} \begin{Bmatrix} \dot{q}_1 \\ \dot{q}_2 \\ \vdots \\ \dot{q}_6 \\ \dot{q}_7 \\ \dot{q}_8 \end{Bmatrix}^{n+1}$$

$$+ \begin{bmatrix} k_{11} & k_{12} & \cdots & k_{16} & k_{17} & k_{18} \\ k_{21} & k_{22} & \cdots & k_{26} & k_{27} & k_{28} \\ \vdots & \vdots & \cdots & \vdots & \vdots & \vdots \\ k_{61} & k_{62} & \cdots & k_{66} & k_{67} & k_{68} \\ k_{71} & k_{72} & \cdots & k_{76} & k_{77} & k_{78} \\ k_{81} & k_{82} & \cdots & k_{86} & k_{87} & k_{88} \end{bmatrix} \begin{Bmatrix} q_1 \\ q_2 \\ \vdots \\ q_6 \\ q_7 \\ q_8 \end{Bmatrix}^{n+1} = \begin{Bmatrix} F_1 \\ 0 \\ \vdots \\ 0 \\ F_7 \\ 0 \end{Bmatrix}^{n+1} \qquad (3.29)$$

The next step creates two sets of equations. The first set, equations 3.30 and 3.31 consists of individual equations in which the displacement, velocity,and accelerations are known but the force is not. The second set, equation 3.32 consists of the matrix equations set equal to the zero force vector. In these equations all displacement, velocity,and acceleration quantities are unknown.

These equations of motion for the system are now written as:

$$F_1 = \langle m_{11} \cdots m_{18} \rangle \begin{Bmatrix} \ddot{q}_1 \\ \cdot \\ \cdot \\ \cdot \\ \ddot{q}_8 \end{Bmatrix}^{n+1} + \langle c_{11} \cdots c_{18} \rangle \begin{Bmatrix} \dot{q}_1 \\ \cdot \\ \cdot \\ \cdot \\ \dot{q}_8 \end{Bmatrix}^{n+1} + \langle k_{11} \cdots k_{18} \rangle \begin{Bmatrix} q_1 \\ \cdot \\ \cdot \\ \cdot \\ q_8 \end{Bmatrix}^{n+1} \tag{3.30}$$

$$F_7 = \langle m_{71} \cdots m_{78} \rangle \begin{Bmatrix} \ddot{q}_1 \\ \cdot \\ \cdot \\ \cdot \\ \ddot{q}_8 \end{Bmatrix}^{n+1} + \langle c_{71} \cdots c_{78} \rangle \begin{Bmatrix} \dot{q}_1 \\ \cdot \\ \cdot \\ \cdot \\ \dot{q}_8 \end{Bmatrix}^{n+1} + \langle k_{71} \cdots k_{78} \rangle \begin{Bmatrix} q_1 \\ \cdot \\ \cdot \\ \cdot \\ q_8 \end{Bmatrix}^{n+1} \tag{3.31}$$

$$\begin{bmatrix} m_{22} & m_{23} & \cdot\cdot & m_{26} & m_{28} \\ m_{32} & m_{33} & \cdot\cdot & m_{36} & m_{38} \\ \cdot & \cdot & \cdot\cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot\cdot & \cdot & \cdot \\ m_{62} & m_{63} & \cdot\cdot & m_{66} & m_{68} \\ m_{82} & m_{83} & \cdot\cdot & m_{86} & m_{88} \end{bmatrix} \begin{Bmatrix} \ddot{q}_2 \\ \ddot{q}_3 \\ \cdot \\ \cdot \\ \ddot{q}_6 \\ \ddot{q}_8 \end{Bmatrix}^{n+1} + \begin{bmatrix} c_{22} & c_{23} & \cdot\cdot & c_{26} & c_{28} \\ c_{32} & c_{33} & \cdot\cdot & c_{36} & c_{38} \\ \cdot & \cdot & \cdot\cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot\cdot & \cdot & \cdot \\ c_{62} & c_{63} & \cdot\cdot & c_{66} & c_{68} \\ c_{82} & c_{83} & \cdot\cdot & c_{86} & c_{88} \end{bmatrix} \begin{Bmatrix} \dot{q}_2 \\ \dot{q}_3 \\ \cdot \\ \cdot \\ \dot{q}_6 \\ \dot{q}_8 \end{Bmatrix}^{n+1} + \begin{bmatrix} k_{22} & k_{23} & \cdot\cdot & k_{26} & k_{28} \\ k_{32} & k_{33} & \cdot\cdot & k_{36} & k_{38} \\ \cdot & \cdot & \cdot\cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot\cdot & \cdot & \cdot \\ k_{62} & k_{63} & \cdot\cdot & k_{66} & k_{68} \\ k_{82} & k_{83} & \cdot\cdot & k_{86} & k_{88} \end{bmatrix} \begin{Bmatrix} q_2 \\ q_3 \\ \cdot \\ \cdot \\ q_6 \\ q_8 \end{Bmatrix}^{n+1}$$

$$+ \Delta P_1^{n+1} + \Delta P_2^{n+1} = \begin{Bmatrix} 0 \\ \cdot \\ \cdot \\ \cdot \\ 0 \end{Bmatrix} \tag{3.32}$$

Where

$$\Delta P_1^{n+1} = \begin{Bmatrix} m_{21} \\ m_{31} \\ \cdot \\ \cdot \\ m_{61} \\ m_{81} \end{Bmatrix} \ddot{q}_1^{n+1} + \begin{Bmatrix} c_{21} \\ c_{31} \\ \cdot \\ \cdot \\ c_{61} \\ c_{81} \end{Bmatrix} \dot{q}_1^{n+1} + \begin{Bmatrix} k_{21} \\ k_{31} \\ \cdot \\ \cdot \\ k_{61} \\ k_{81} \end{Bmatrix} q_1^{n+1} \qquad (3.33)$$

and

$$\Delta P_2^{n+1} = \begin{Bmatrix} m_{27} \\ m_{37} \\ \cdot \\ \cdot \\ m_{67} \\ m_{87} \end{Bmatrix} \ddot{q}_7^{n+1} + \begin{Bmatrix} c_{27} \\ c_{37} \\ \cdot \\ \cdot \\ c_{67} \\ c_{87} \end{Bmatrix} \dot{q}_7^{n+1} + \begin{Bmatrix} k_{27} \\ k_{37} \\ \cdot \\ \cdot \\ k_{67} \\ k_{87} \end{Bmatrix} q_7^{n+1} \qquad (3.34)$$

The set of consistent system equations written in concise form are

$$F_1 = \sum_{i=1}^{8} (m_{1i} \ddot{q}_i^{n+1} + c_{1i} \dot{q}^{n+1} + k_{1i} q^{n+1}) \qquad (3.35)$$

$$F_7 = \sum_{i=1}^{8} (m_{7i} \ddot{q}_i^{n+1} + c_{7i} \dot{q}^{n+1} + k_{7i} q^{n+1}) \qquad (3.36)$$

and

$$[m_{ij}] \{\ddot{q}_i\}^{n+1} + [c_{ij}] \{\dot{q}_i\}^{n+1} + [k_{ij}] \{q_i\}^{n+1} + \sum_{j=1}^{2} \Delta P_j^{n+1} = \{0_i\} \qquad (3.37)$$

$$(i = 2,3,..6,8;\ j = 2,3,..6,8)$$

The next step is the solution of the matrix equation 3.37 by Newmark's method, for the unknown accelerations. By integration the velocities and displacements are written in terms of the accelerations as:

$$\{\dot{q}_i\}^{n+1} = \{\dot{q}_i\}^n + \frac{\Delta T}{2}\{\ddot{q}_i\}^n + \frac{\Delta T}{2}\{\ddot{q}_i\}^{n+1} \tag{3.38}$$

and

$$\{q_i\}^{n+1} = \{q_i\}^n + \Delta T\{\dot{q}_i\}^n + \frac{\Delta T^2}{3}\{\ddot{q}_i\}^n + \frac{\Delta T^2}{6}\{\ddot{q}_i\}^{n+1} \tag{3.39}$$

$$(i = 2,3, \ldots 6,8)$$

Let

$$\{\alpha_i\}^n = \{\dot{q}_i\}^n + \frac{\Delta T}{2}\{\ddot{q}_i\}^n \tag{3.40}$$

and

$$\{\beta_i\}^n = \{q_i\}^n + \Delta T\{\dot{q}_i\}^n + \frac{\Delta T^2}{3}\{\ddot{q}_i\}^n \tag{3.41}$$

$$(i = 2,3, \ldots 6,8)$$

Substituting for $\{\alpha\}^n$ and $\{\beta\}^n$ equations 3.38 and 3.39 become:

$$\{\dot{q}_i\}^{n+1} = \{\alpha_i\}^n + \frac{\Delta T}{2}\{\ddot{q}_i\}^{n+1} \tag{3.42}$$

$$\{q_i\}^{n+1} = \{\beta_i\}^n + \frac{\Delta T^2}{6}\{\ddot{q}_i\}^{n+1} \tag{3.43}$$

$$(i = 2,3,..6,8)$$

Next substituting for $\{\dot{q}_i\}^{n+1}$ and $\{q_i\}^{n+1}$ into equations 3.37 and factoring yields:

$$\left([m_{ij}] + [c_{ij}]\frac{\Delta T}{2} + [k_{ij}]\frac{\Delta T^2}{6}\right)\{\ddot{q}_i\}^{n+1} + [c_{ij}]\{\alpha_i\}^n + [k_{ij}]\{\beta_i\}^n + \sum_{k=1}^{2} \Delta P_k^{n+1} = \{0_i\} \quad (3.44)$$

$$(i = 2,3 \ldots 6,8;\ j = 2,3, \ldots 6,8)$$

Let

$$[BMIV_{ij}]^{-1} = [m_{ij}] + [c_{ij}]\frac{\Delta T}{2} + [k_{ij}]\frac{\Delta T^2}{6} \quad (3.45)$$

$$(i = 2,3, \ldots 6,8;\ j = 2,3, \ldots 6,8)$$

Substituting for $[BMIV]^{-1}$ in equation 3.44 and moving the knowns to the right side of the equation yields

$$[BMIV_{ij}]^{-1}\{\ddot{q}_i\}^{n+1} = -[c_{ij}]\{\alpha_i\}^n - [k_{ij}]\{\beta_i\}^n - \sum_{k=1}^{2} \Delta P_k^{n+1} \quad (3.46)$$

$$(i = 2,3,..6,8\ ;\ j = 2,3,..6,8)$$

Inverting the matrix $[BMIV]^{-1}$ yields the expression for the unknown accelerations

$$\{\ddot{q}_i\}^{n+1} = -[BMIV_{ij}][c_{ij}]\{\alpha_i\}^n - [BMIV_{ij}][k_{ij}]\{\beta_i\}^n - [BMIV_{ij}]\left(\sum_{k=1}^{2} \Delta P_k^{n+1}\right) \quad (3.47)$$

$$(i = 2,3,..6,8;\ j = 2,3,..6,8)$$

In equation 3.47 the non-time function matrix multiplications operations are precalculated as

$$[DA_{ij}] = [BMIV_{ij}]\,[c_{ij}] \quad (3.48)$$

and

$$[DV_{ij}] = [BMIV_{ij}]\,[k_{ij}] \quad (3.49)$$

$$(i = 2,3,..6,8;\ j = 2,3,..6,8)$$

The system accelerations, except the initial known values, are now calculated by

$$\{\ddot{q}_i\}^{n+1} = -[DA_{ij}] - [DV_{ij}] - [BMIV_{ij}] \left(\sum_{k=1}^{2} \Delta P_k^{n+1} \right) \qquad (3.50)$$

$$(i = 2,3,..6,8;\ j = 2,3,..6,8)$$

The system velocities and displacements are calculated from

$$\{\dot{q}_i\}^{n+1} = \{\alpha_i\} + \frac{\Delta T}{2} \{\ddot{q}_i\}^{n+1} \qquad (3.51)$$

$$\{q_i\}^{n+1} = \{\beta_i\} + \frac{\Delta T^2}{6} \{\ddot{q}_i\}^{n+1} \qquad (3.52)$$

$$(i = 2,3,...6,8;\ j = 2,3,...6,8)$$

The remaining system unknowns, F_1 and F_7 may be directly calculated from equations 3.30 or 3.35 and 3.31 or 3.36. This completes the calculations for the required solution to the problem for this time step.

2. Precalculated Matrices

Returning to equation 3.32 it is noted that the mass, damping, and stiffness matrices are unique to configuration VI. Similarly from equation 3.30 and 3.31 the mass, damping, and stiffness column vectors are also unique to configuration VI. Thus these matrices need only be calculated once if stored as layers to the full system matrices. Figure 3.4 graphically indicates the matrix dimensions and elements for this and the remaining seven configurations. Additionally for the eight sets of precalculated matrices [M], [C], and [K] the matrix variables [BMIV], [DA], and [DV] given by equations 3.45, 3.48, and 3.49 may be precalculated for the standard ΔT and stored.

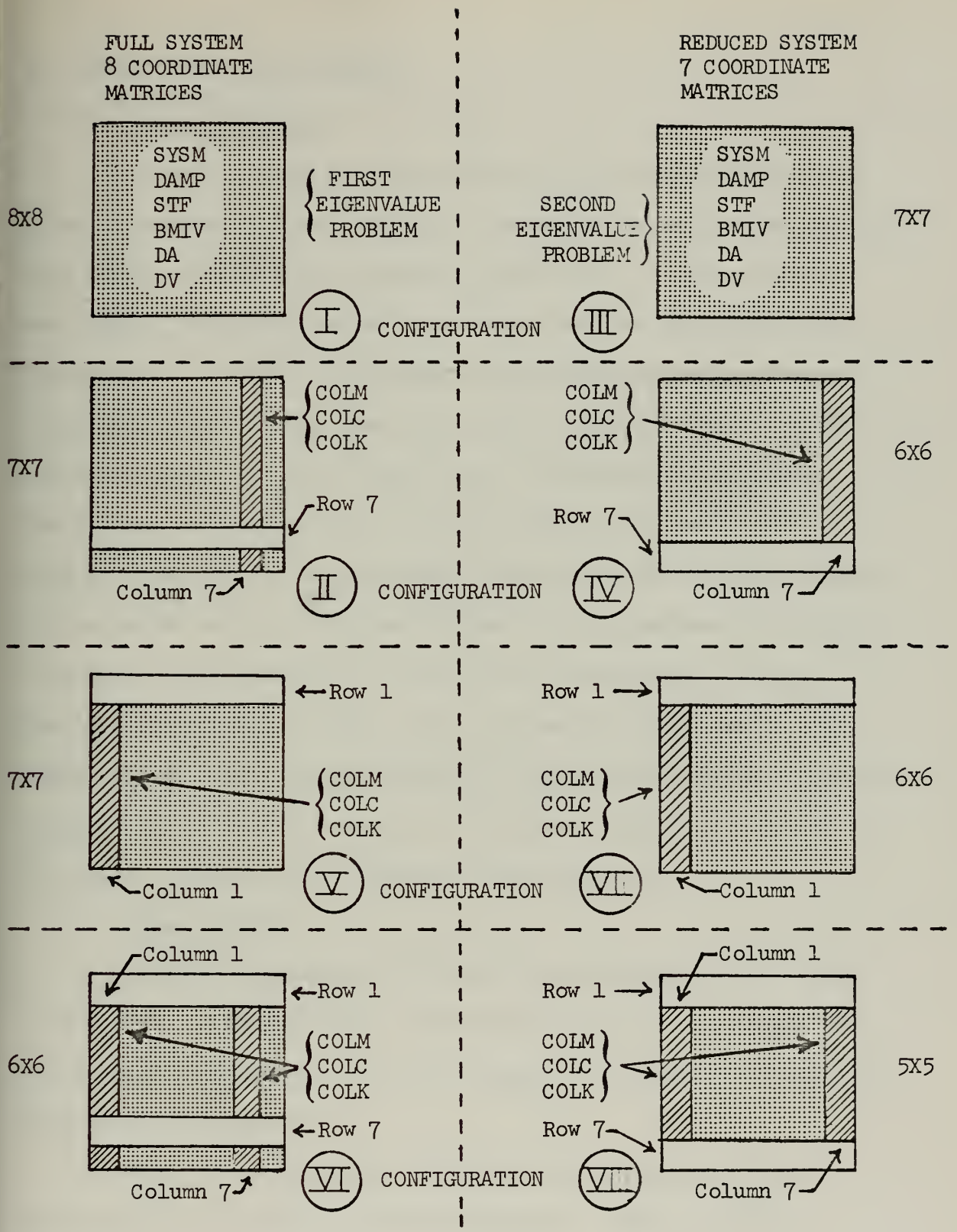


Figure 3.4 MATRIX LAYERS

F. REFINEMENTS IN THE SOLUTION

1. Incremental Time

As seen in section 3.E, equation 3.27, the normal time step is established as 1×10^{-6} seconds. Generally the system configuration will change in a time step interval, rather than at either of the end points. When this occurs the present negative monitored value calculated at $t = t^{n+1}$ and the past stored monitored value that was calculated at $t = t^{n}$ are used for a linear interpolation to obtain the zero point, i.e. zero force or zero displacement difference. The ΔT, now designated as $\Delta T'$, corresponding to the zero point is used to calculate the system values based on the old configurations. If the system has more than one change in configurations for a given time step, the minimum $\Delta T'$ is used for the calculations, $\Delta T'_{min}$. The newly calculated critical value is then monitored, and if still negative, the time is again reduced by a small amount until a positive value of the monitored parameter is obtained. Figure 3.5 summerizes the above procedures for a negative force parameter.

2. Impact Forces

Anderson, in Chapter IV (Ref. 2), puts forth a good account of the study of impact forces. Numerous references are cited. Thus the historical background of impact forces in relation to this study will not be discussed here.

When the displacement difference values reduce to zero (or negative), contact at a clearance exists. This produces a step input to the velocity function and an impulse to the acceleration

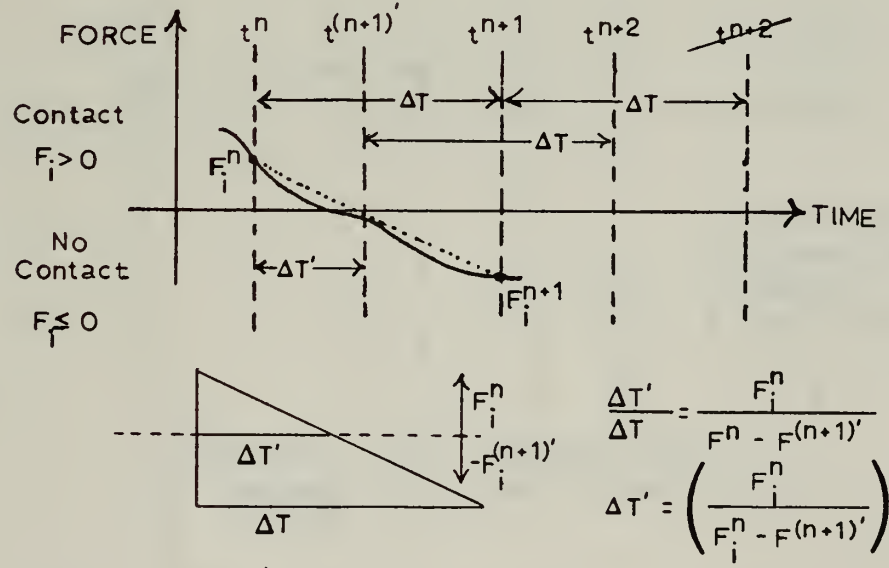
function. Finite time steps are utilized to obtain solutions. Therefore one time step is sufficient to reach the step input value for the velocity curve, but two time intervals are required to account for the acceleration caused by the impulse, Figure 3.6. Thus the acceleration at time t^{n+1} is

$$\ddot{q}_i^{\,n+1} = (\dot{q}_i^{\,n+1} - \dot{q}_i^{\,n}) \,/\, \Delta T \qquad (i = 1,2,7) \tag{3.53}$$

This accelation is readily calculated for impact at the cam or valve seat (i = 1 or 7). However for contact at the rocker, neither $\ddot{q}_2^{\,n+1}$ or $\dot{q}_2^{\,n+1}$ is known. In order to solve the equation the assumption is made that

$$\dot{q}_2^{\,n+1} = \text{SCALE} * \dot{q}_2^{\,n} \quad . \tag{3.54}$$

The value for SCALE is arbitrarily chosen from 1.0 to 2.0, until a good system response results. Further study is suggested in this area.



then $\omega t^{(n+1)'} = \omega t^n + \omega \Delta T'$

is used to calculate system values.

Figure 3.5 Incremental Time $\Delta T'$

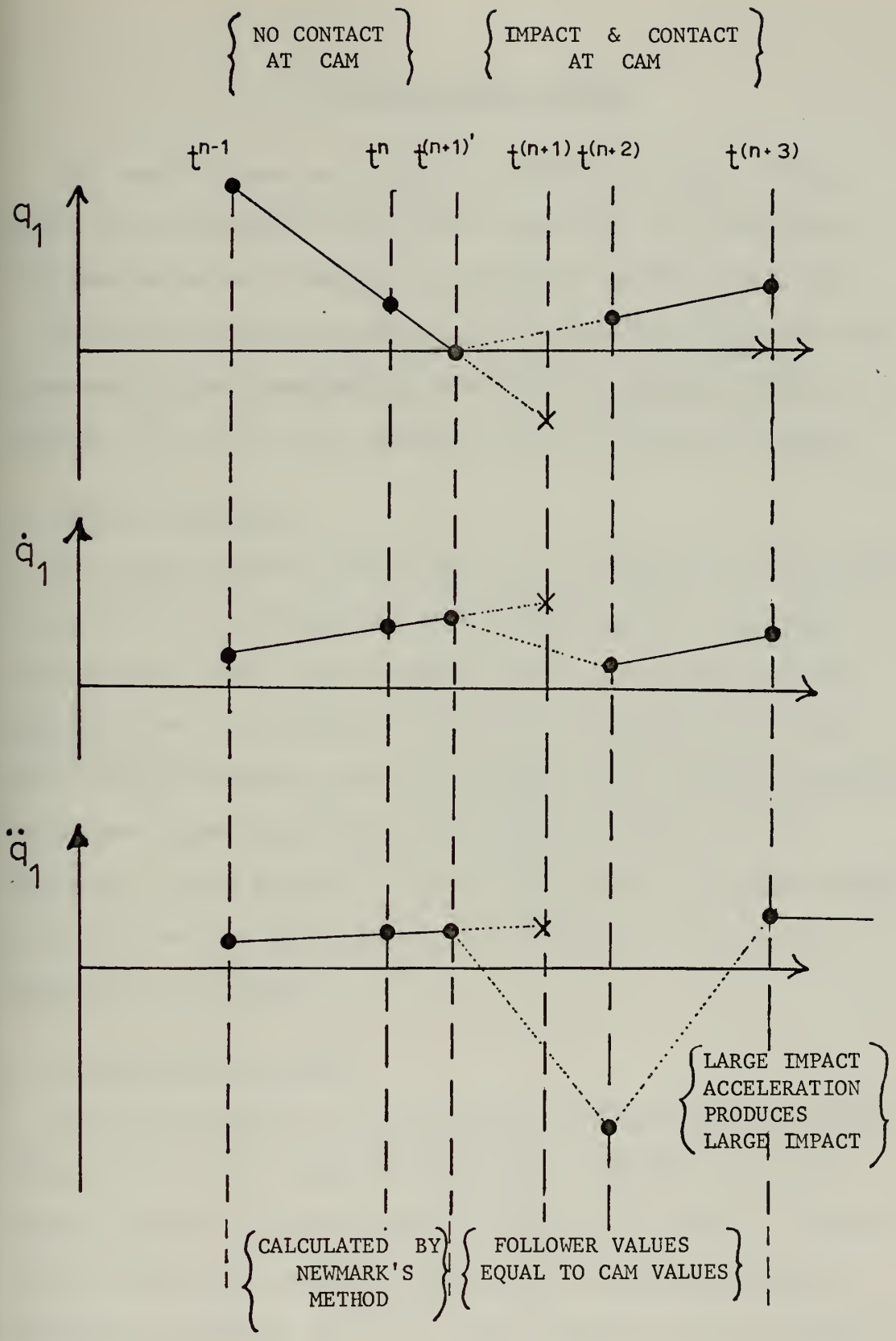


Figure 3.6 System Curves For Impact Considerations

IV. IBM-360 COMPUTER PROGRAM

This computer program is coded in FORTRAN IV, (Refs. 10-13), to run on an IBM-360/67, with OS/360 release 18. The simulation is modeled after basic concepts put forth by Anderson, (Ref. 2).

The original model program has been completely restructured and formulated to yield general procedures for the analysis of the dynamics of an elastic link mechanism with an internal clearance.

A. GENERAL DESCRIPTION

The program requires 234 K bytes of core storage for 850 degrees of cam rotation, including the CALCOMP graph buffer. The offline printer array (GRID) is not included in this core storage figure. Execution time is a function of the speed of rotation of the cam. For 11,000 RPM with 850 degrees, execution time is about 4.3 minutes. The primary output parameters fill arrays for SYSOUT = B and SYSOUT = C. The B queue is for transfering data, via punched cards, for use in the SDS-9300 computer. The C queue is for plotting graphs via the CALCOMP.

B. GENERALIZATION MATRICES

As noted in section 3.D, the number of system configurations is 2^n, where "n" is the number of clearances. Therefore, the most general computer programming was utilized, where possible. Several arrays of prestored computer "instructions" are either computer generated or formed by the user. These arrays set looping variables,

dynamically dimension work arrays, and establish program calculation flow indicators.

1. Matrix CONFIG

The 8 by 3 matrix CONFIG, Figure 4.1 was described in section 3.D. This integer array indicates the physical configurations that the model has taken based on the value of the monitored parameters. The matrix is formed by the program. The user must supply the value for the maximum number of configurations the system is permitted to take.

0	0	0
0	0	1
0	1	0
0	1	1
1	0	0
1	0	1
1	1	0
1	1	1

Figure 4.1 Matrix CONFIG

2. Matrix IDM

The 8 by 1 column vector IDM indicates the dimension of the matrices that are used for calculations. This array is indicated in Figure 4.2 for the three clearance system. The program parameter ISYS is the matrix dimension of the equivalent system mass, stiffness, and damping matrices and for the calculated program matrix variables BMIV, DA, and DV. The dimensions of the various layers correspond to their configuration number and to the rows of IDIM, i.e. when the system is in configuration I, layer one matrices have the dimension indicated in row one of IDIM. This integer array is calculated by the program.

$$\begin{Bmatrix} 8 \\ 7 \\ 7 \\ 6 \\ 7 \\ 6 \\ 6 \\ 5 \end{Bmatrix}$$

Figure 4.2 Matrix IDIM

3. Matrix LAYER

The 8 by 1 array LAYER, Figure 4.3, is an integer column vector supplied by the user. The elements of the vector consist of ones or threes. As the name implies, the layer of the mass, stiffness, damping, BMIV, DA, and DV matrices used in the calculations correspond to the configuration number the system has taken. The eigenvalue

problem for contact at the internal clearance (layer 1) or no contact (layer 3), determines the elements of LAYER. Configurations III, IV, VII , or VIII for contact at the rocker-pushrod, use the same eigenvalue problem for the reduced system, i.e. the damping matrix is calculated with layer 3 matrices. Configurations I, II, V, or VI for no contact at the rocker-pushrod, use the full system eigenvalue problem. The damping matrix is calculated using layer 1 matrices. Figure 4.3 shows these values of LAYER for the three clearance model with two eigenvalue problems.

$$\begin{Bmatrix} 1 \\ 1 \\ 3 \\ 3 \\ 1 \\ 1 \\ 3 \\ 3 \end{Bmatrix}$$

Figure 4.3 Matrix LAYER

4. Matrix IQ

The 8 by 8 integer array IQ, Figure 4.4 indicates the system coordinates for which the Newmark routine will calculate the unknown quantities i.e. displacements, velocities, accelerations, and forces for a given time step. The columns of the array correspond to the configuration number except column 1 and 3. These are additional columns used with configurations VI and VIII respectively. The array is user supplied.

1	1	1	1	2	2	2	2
2	2	2	2	3	3	3	3
3	3	3	3	4	4	4	4
4	4	4	4	5	5	5	5
5	5	5	5	6	6	6	6
6	6	6	6	7	8	7	0
7	8	7	0	8	0	0	0
8	0	0	0	0	0	0	0

Figure 4.4 Matrix IQ

5. Matrix IDP

This 8 by 3 integer array, Figure 4.5, consists of zero elements except where impact may be expected to occur at the external clearances. Here again the rows correspond to the configuration number and the columns correspond to the clearance number. The matrix IDP is used in the calculation of ΔP as a portion of Newmark's method. The array is calculated by the program.

0	0	0
0	0	7
0	0	0
0	0	7
1	0	0
1	0	7
1	0	0
1	0	7

Figure 4.5 Matrix IDP

6. Matrix ICORD

The 3 by 2 integer array ICORD, Figure 4.6 indicates the coordinate pairs of the internal and external clearances. The elements are stored row wise by pairs. The rows correspond to the clearance numbers 1, 2, and 3 respectively. The first column corresponds to the index of the system coordinate that has the greater positive displacement when no contact exists at the clearance in question. The second column is assigned to the remaining index of the clearance pair. The array ICORD is user generated. Figure 4.6 shows the matrix for the three clearance problem defined in chapter 2.

1	9
2	8
7	10

Figure 4.6 Matrix ICORD

7. Matrix IMPACT

The 3 by 1 column vector IMPACT is program generated. The integer elements are continuously modified during program execution. The rows correspond to the clearance number pairs. Values 1, 2, or 7, of the system coordinates are stored when impact occurs for a given time step at a corresponding clearance.

C. DYNAMIC DIMENSIONING

The principle of dynamic dimensioning is widely used in advanced programming and often misunderstood. Thus a short example of its concepts as applied to this work is presented here. Reference to Figures 4.7 and 4.8 will aid in the understanding of the concepts.

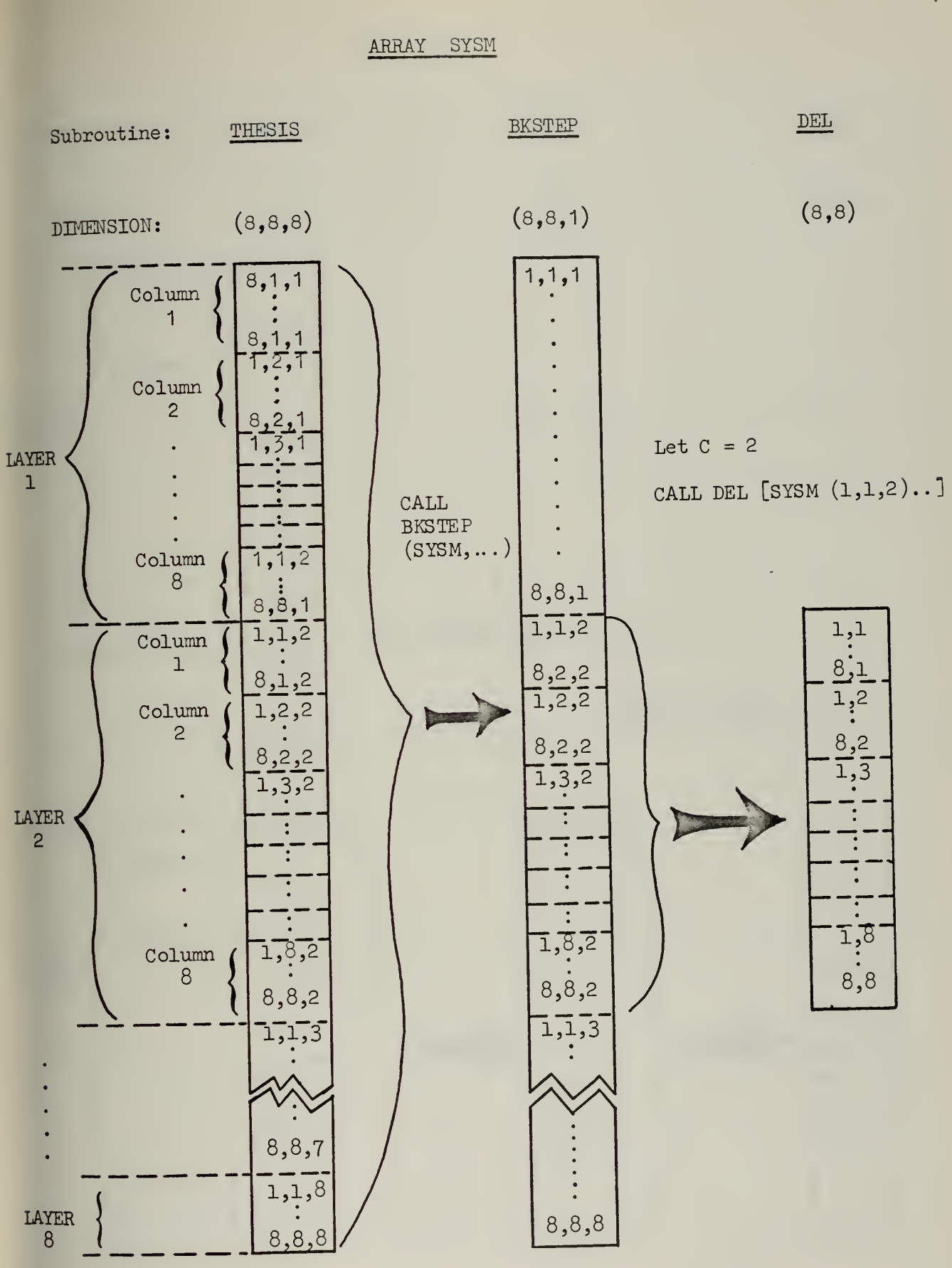


Figure 4.7 Dynamic Dimensioning of Array SYSM

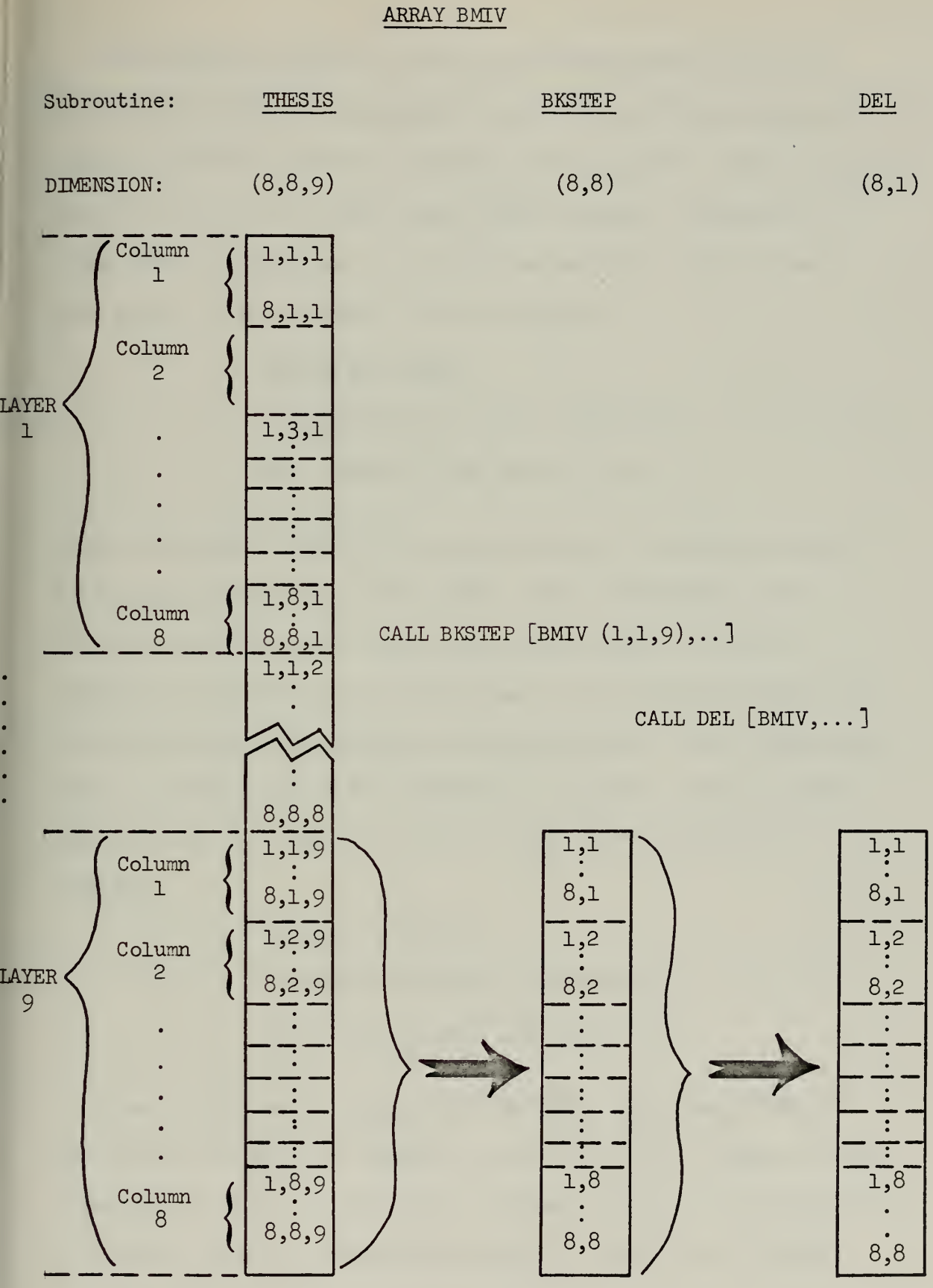


Figure 4.8 Dynamic Dimensioning of Array BMIV

In subroutine THESIS the mass array SYSM and the calculation array BMIV are exactly dimensioned indicating the total number of elements which are stored by columns in the computer. When subroutine BKSTEP is called, the entire array SYSM is passed. However the array BMIV is initialized in the call as the first value of the last layer, in this example. This is shown as:

```
Subroutine THESIS
DIMENSION SYSM (8,8,8), BMIV(8,8,9)
CALL  BKSTEP (SYSM, BMIV(1,1,9), ...)
```

Thus in subroutine BKSTEP, the array SYSM must be dimensioned with the exact number of rows and columns. Since the computer has already provided for the total space of the array, the third dimension is dynamic and if entered may be any positive number equal to or less than the originally assigned dimension. Since the entire array is utilized the third dimension is retained. For the array BMIV only the last layer is used, thus the third dimension is dropped.

```
Subroutine BKSTEP
DIMENSION  SYSM(8,8,1), BMIV(8,8)
CALL  DEL (SYSM(1,1,C), BMIV, ...)
```

When subroutine DEL is called from BKSTEP the array, SYSM is now initialized with the variable C, (C = 1,2,...8). BMIV, now only considered an 8 by 8 array, is not initialized here. The dimensioning in subroutine DEL is accomplished similar to that done in BKSTEP.

The array SYSM must again be dimensioned as above with the third dimensioning parameter being dynamic. The array BMIV is used as a double dimensioned array in subroutine DEL. By arguments similar to those above, the columns of the array may now also be dynamically dimensioned as:

```
Subroutine DEL
DIMENSION SYSM(8,8), BMIV(8,1)
```

Figure 4.7 for array SYSM and Figure 4.8 for array BMIV graphically indicate the manner in which these arrays are passed from the subroutines, THESIS-BKSTEP-DEL.

D. PROGRAM STRUCTURE

The main program only sets up the plotting arrays and then calls subroutine THESIS, the main routine that controls the program execution. The calling order is presented in Figure 4.9. The CALCOMP graphing subroutines indicated by an asterisk are supplied by the computer center.

E. SUBROUTINES

The function of each of the subroutines and a description of their execution are included in this section. The concept of execution of object modules stored on disk was used to a large extent. This accounts for the large number of subroutines and their limited content. Flow graphs for the majority of the routines are collected and presented at the end of this section. Each subroutine is listed in its entirety in the IBM-360 Computer Program Listing chapter.

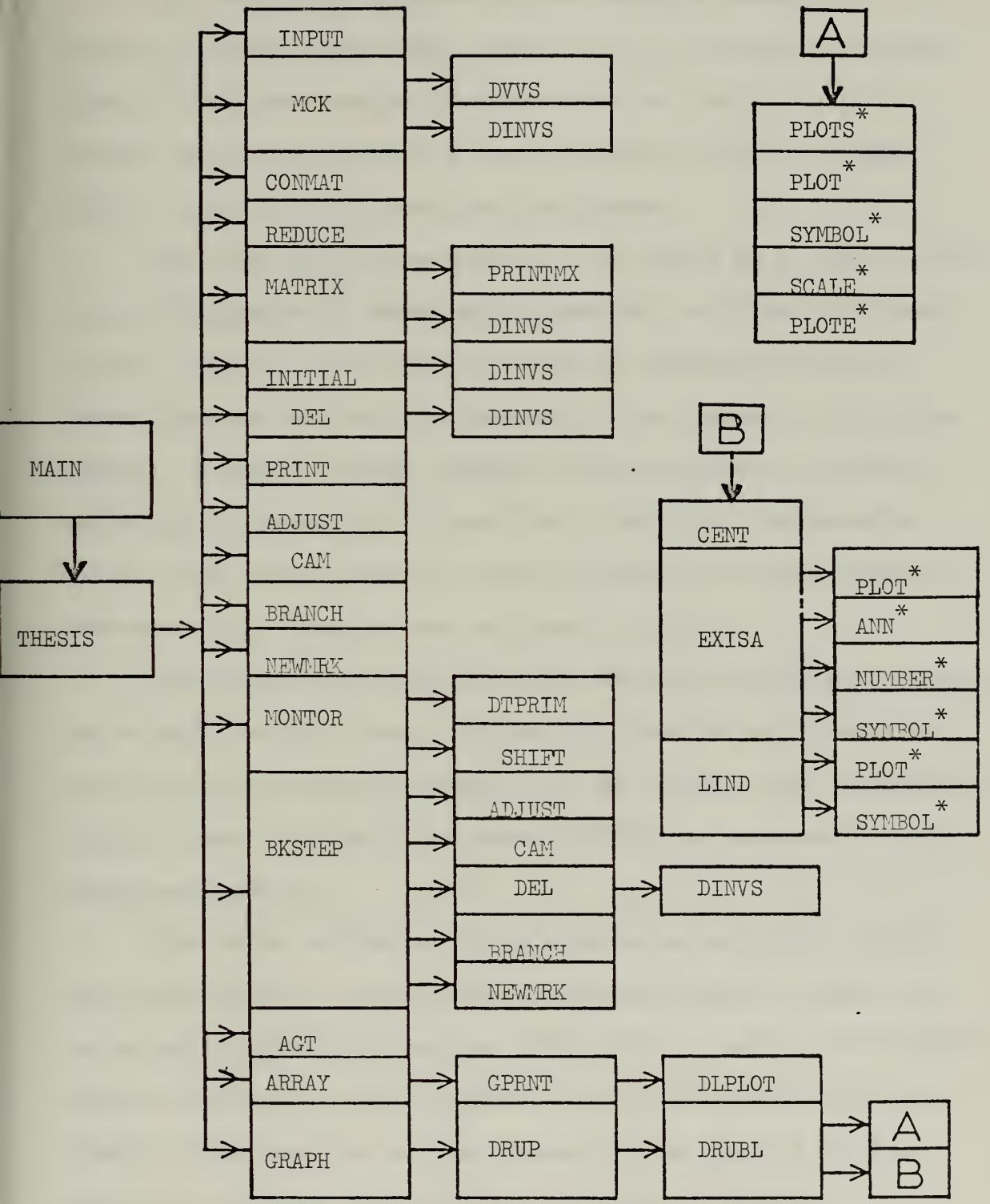


Figure 4.9 IBM-360 Computer Program Structure

1. Subroutine THESIS

This subroutine controls program execution, establishes calculation arrays (MCK, CONMAT, MATRIX, DEL), initialing parameters (INPUT, INITAL) and contains the major time step loop, $\Delta T = 10^{-6}$ seconds. As seen in Figure 4.9, most subroutines are called from THESIS. Figure 4.10 indicates the flow diagram.

The time parameter ωt advances by an amount $\omega \Delta T$. The previous values of displacement, velocity, acceleration, and force are stored (ADJUST). The new cam values are calculated (CAM) and the known system parameter are initialed according to the present configuration (BRANCH). Newmark's method (NEWMARK) is then employed to calculate the remaining unknown system quantities. The system configuration value is next stored prior to checking the newly calculated quantities (MONTOR) for any change in the configuration number.

The system is now checked to see whether an impact has occurred and at what coordinate index. If the configuration has changed, the quantities are recalculated (BKSTEP) for the time that the configuration changed. Then force values are reset (FIXFOR) to coorespond to the system configuration.

The amount of degrees of cam rotation is calculated. If the next whole degree has been reached the system values are output for use as the graphics (AGT) and draw (ARRAY) data. Next if the required number of degrees have been evaluated the desired graphs are plotted (GRAPH). Otherwise, the program branches to the start of the time step loop (statement number 360) and the cycle is repeated.

2. Subroutine BKSTEP

This subroutine is similar to subroutine THESIS in that all program variables are recalculated to correspond to the time at which the system configuration changed. Once this routine is entered only the parameter corresponding to the configuration shift is monitored until a positive value is calculated. Figure 4.11 indicates the flow diagram.

3. Subroutine MCK, DVVS, and DINVS

This subroutine originally coded by Anderson and Winfrey, was modified to account for the additional eigenvalue problem. The sizes and material properties of the system members are assigned. The element of the full and reduced system mass and stiffness are assigned to their respective arrays, SYSM and STF. The damping ratio, (ZTA) is set on the basis of the fundamental frequency of the system being considered. The eigenvalue problems are solved by subroutine DVVS. Subroutine DINVS is called to obtain matrix inverses..

4. Newmark's Method Subroutines

Subroutines NEWMRK and DEL are the primary program calculation routines, and considered together comprise Newmark's method. The flow diagram for subroutine DEL is seen in Figure 4.12 and for subroutine NEWMRK, Figure 4.13.

(a) Subroutine DEL

Subroutine DEL calculates the eight layers of the matrix arrays BMIV, DA, and DV, based on the full time step ΔT. These matrices are precalculated and stored. When DEL is called from subroutine BKSTEP, an additional layer of the above matrices is calculated as required, with a partial time step, $\Delta T_{min} < 10^{-6}$ seconds.

(b) Subroutine NEWMRK

Subroutine NEWMRK calculates the coordinate accelerations by Newmark's method. The theory of this method is presented in appendix B. Its relation to this study is presented in section 3.E. After the system accelerations are known, the displacements and velocities can be calculated. Finally the forces are calculated at clearance coordinates 1, 2, and 7.

5. Subroutine for Shifting Configurations

The two subroutines that provide the program the ability to shift from one configuration to another, based on the values of the monitored parameters, are MONTOR and SHIFT. Figure 4.14 indicates the flow diagram for subroutine MONTOR. The subroutine that determines the amount by which the time step should be reduced, after a change in the configuration has been indicated, is DTPRIM. The flow diagram for this subroutine is seen in Figure 4.16.

(a) Subroutine MONTOR

Subroutine MONTOR checks the forces and/or the displacement differences at the three clearances to determine if any has become negative. As indicated by the shifting flow diagram, Figure 2.6, only three quantities must be monitored at each clearance, either forces and/or displacements differences. When at least one of the values becomes negative, subroutine DTPRIM is called.

(b) Subroutine DTPRIM

Subroutine DTPRIM linearly interpolates for a best estimate of the time the monitored value became negative, i.e. when the system changed to a different configuration. The calculated time

is stored in array DTP. If more than one change to the system configuration occurs in a single time step, the first change is chosen, i.e. the minimum value among the elements of the array DTP. The clearance index number that causes the system to change is then sent to subroutine SHIFT.

(c) Subroutine SHIFT

Subroutine SHIFT, described in section 3.D returns the new configuration based on the parameters sent by MONTOR.

6. Subroutine INPUT

This subroutine reads as data the formal parameters that are frequently varied. Figure 4.17 presents the flow diagram for this subroutine. These parameters include revolutions per minute (RPM) of the cam, clearance indicators (CLEAR, PIN 2&8) printing indicators (MPRINT, WTDEG, KPRINT, NCOUNT, IPRINT), output data indicators (IDRAW, AGTOUT, CARDS, TAPE IPLOT) and the tipe step (DELT). Graph titles are read into the arrays XNAME, YNAME, LABEL, and TITLE. The array TITLE is modified to indicate programs without a valve seat. The array LABEL is modified to indicate a two clearance problem. The lengths of the member elements are assigned (REALTH, AGTLTH) and the lever arm of the rocker (ROCKER) is calculated.

7. Subroutine CONMAT

This subroutine establishes two of the program generalization arrays, CONFIG and IDP. Figure 4.18 shows the flow diagram. The routine is called only once during the program execution. The coding for both arrays may be easily expanded to provide for problems with more than three clearances.

8. Subroutine INITAL

This subroutine initiates the starting values of displacement, velocity, acceleration, and force for the system coordinates. The starting configuration VII, requires that layer seven matrices be used for all calculations. Subroutine DINVS is called to establish the inverse stiffness matrix necessary for the displacement calculations. The program variables for the follower are set equal to the cam values and those for the left rocker arm are set equal to the pushrod values by calling subroutine ADJUST.

9. Subroutine CAM

This short subroutine calculates the displacement, velocity, and acceleration at the cam (coordinate 9) for the given ωt. The flow diagram is presented as Figure 4.15. The displacement is given by the equation:

$$q_9 = .5 \sin \omega t + XZERO$$

This routine is called at least once, every time increment from subroutine THESIS. Additionally cam is called by subroutine BKSTEP for intermediate values of ωt.

10. Subroutine BRANCH

This subroutine is called prior to making calculations for a new time step. Figure 4.19 indicates the flow diagram. The eight sections of the routine initialize the system parameters corresponding to its present configuration. Additionally the dimension parameter ISYS is set from the array IDIM. A correction ot the above established acceleration is accomplished when the array IMPACT indicates that a

clearance displacement difference is zero. The adjustment of the acceleration produces a corresponding increase in the later calculated force.

11. Subroutine ADJUST

This short subroutine equivalences the displacement, velocity, and acceleration quantities at a system coordinate to those at another system coordinate. For example, when contact exists between cam and follower the above named quantities for coordinate one are set equal to those for coordinate nine. Figure 4.20 presents the flow diagram.

12. Subroutine FIXFOR

This subroutine is primarily used to zero the calculated forces on the basis of the system configuration. This is necessary to eliminate small negative or small positive forces from being plotted. This routine has no effect on the program calculations. Its flow diagram is seen as Figure 4.21.

13. Output Subroutines

(a) Subroutine AGT

The subroutine AGT outputs data on punched cards or magnetic tape for use in the SDS-9300 program calculations of the graphic display. The flow diagram is indicated in Figure 4.22. This subroutine first adjusts the system displacement coordinates by an amount XZERO so as to present the initial position of the graphics display as horizontal. In addition to the displacement coordinates, reference values are sent for the cam rotation and the valve seat position.

(b) Subroutines ARRAY, GRAPH, GPRINT, OLPLOT

The subroutine ARRAY is called for the first value of each whole degree and establishes the array FPLOT, which is used for the plotting of graphs on the CALCOMP or offline printer. Figure 4.23 presents the flow diagram. Subroutine GRAPH is the last subroutine called by THESIS after the desired number of degrees has been evaluated. This subroutine, as seen in the flow diagram, Figure 4.24, organizes the calls to the offline printer subroutine OLPLOT for IPLOT equal to YES and/or the CALCOMP subroutine GPRINT for IDRAW equal to YES. The flow diagram for subroutine GPRINT is indicated in Figure 4.25. Subroutine OLPLOT is a modified version of the Computer Center provided routine UTPLOT. One of the modifications provides for an expansion of the graph output to a maximum of six pages. The number of pages desired is assigned to the program parameter, IP, by the user. Additionally the users must adjust the dimensions of the main program array, GRID to conform with the desired pages. GRID must be dimensioned as LINES by 81 where the dimension parameter LINES is:

$$LINES = (80)(IP) + 1$$

(c) Subroutine DRU--

The many subroutines beginning with DRU-- were written for plotting graphs on the CALCOMP plotter by Winfrey. This package also contains computer center provided routines, indicated by an asterick in Figure 4.9.

(d) Subroutine LIST (DEBUG)

Subroutine LIST outputs the numerical formal parameters on the offline printer for either "debugging" purposes or as reference values when viewing the graphs/graphics.

(e) Subroutine PRNTMX

Subroutine PRNTMX outputs all the system matrices, when the program parameter MPRINT is equal to YES.

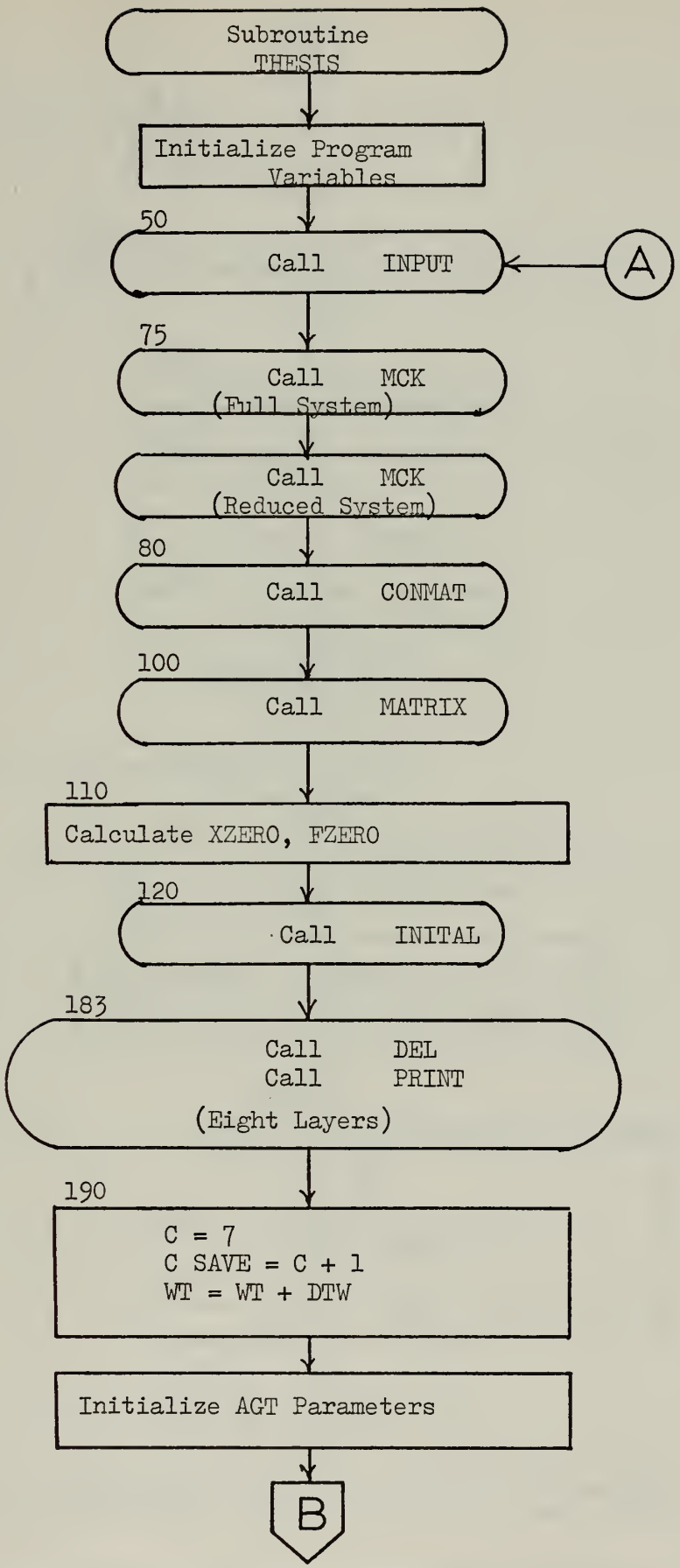


Figure 4.10 Subroutine THESIS Flow Diagram

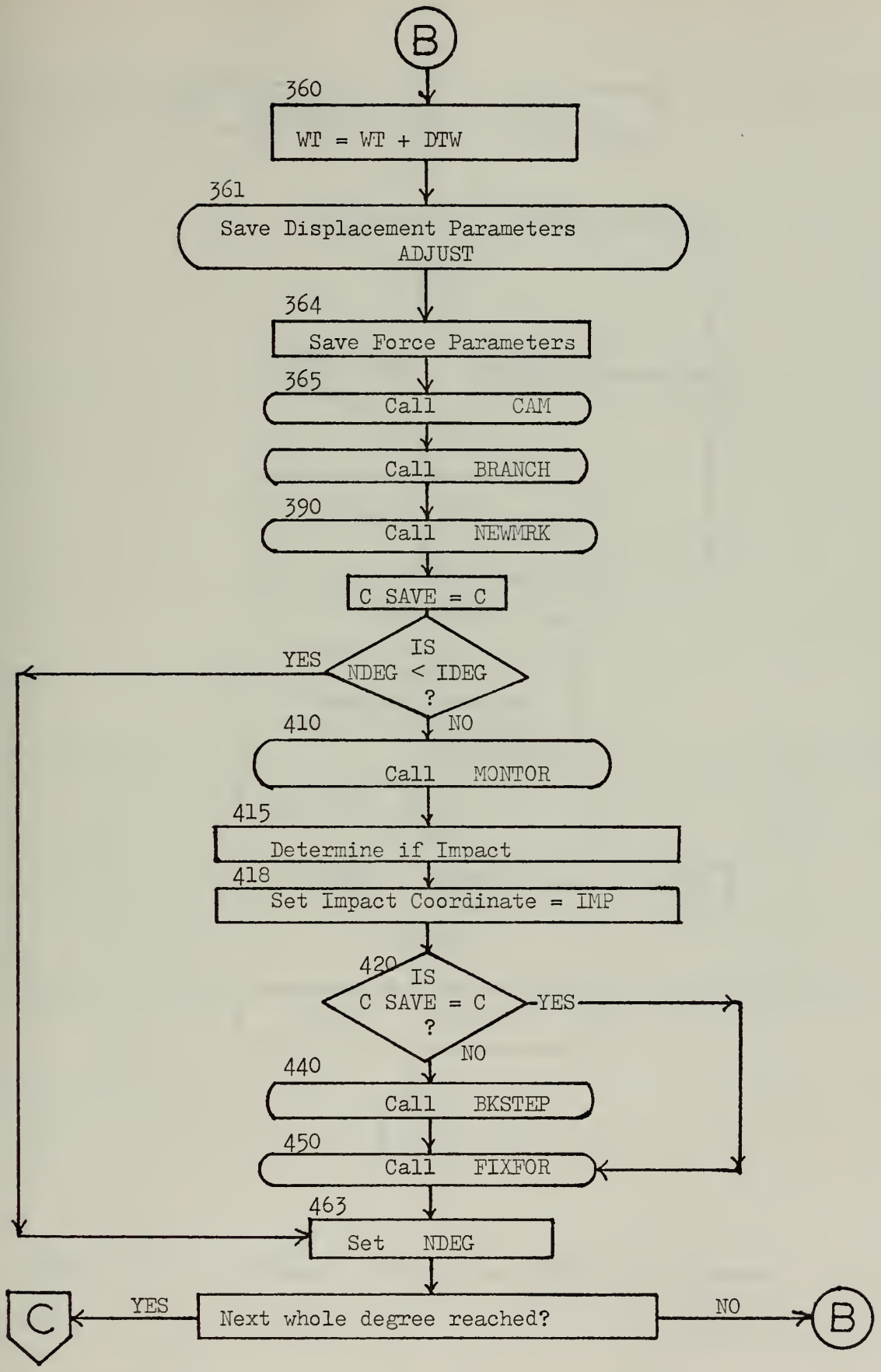


Figure 4.10 Continued - Subroutine THESIS Flow Diagram

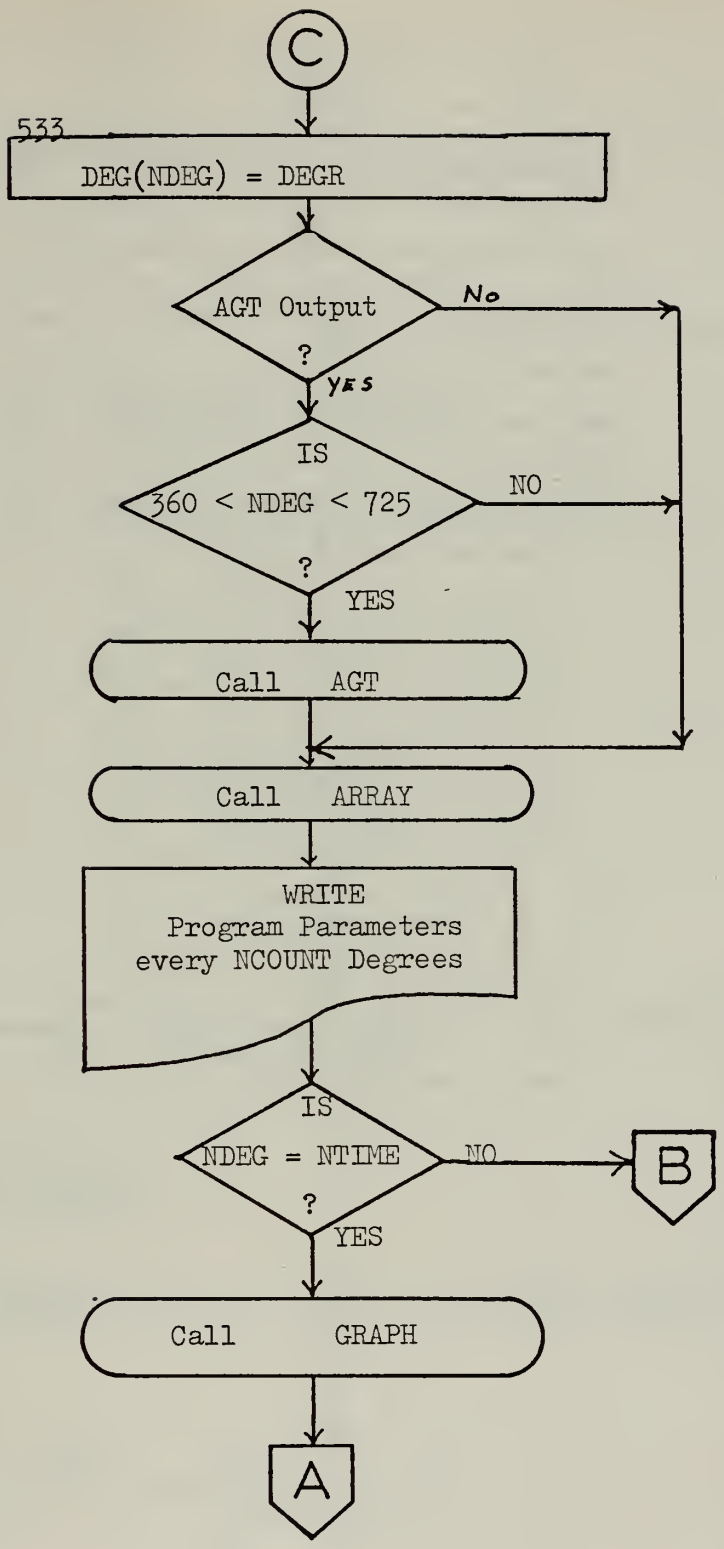


Figure 4.10 Continued - Subroutine THESIS Flow Diagram

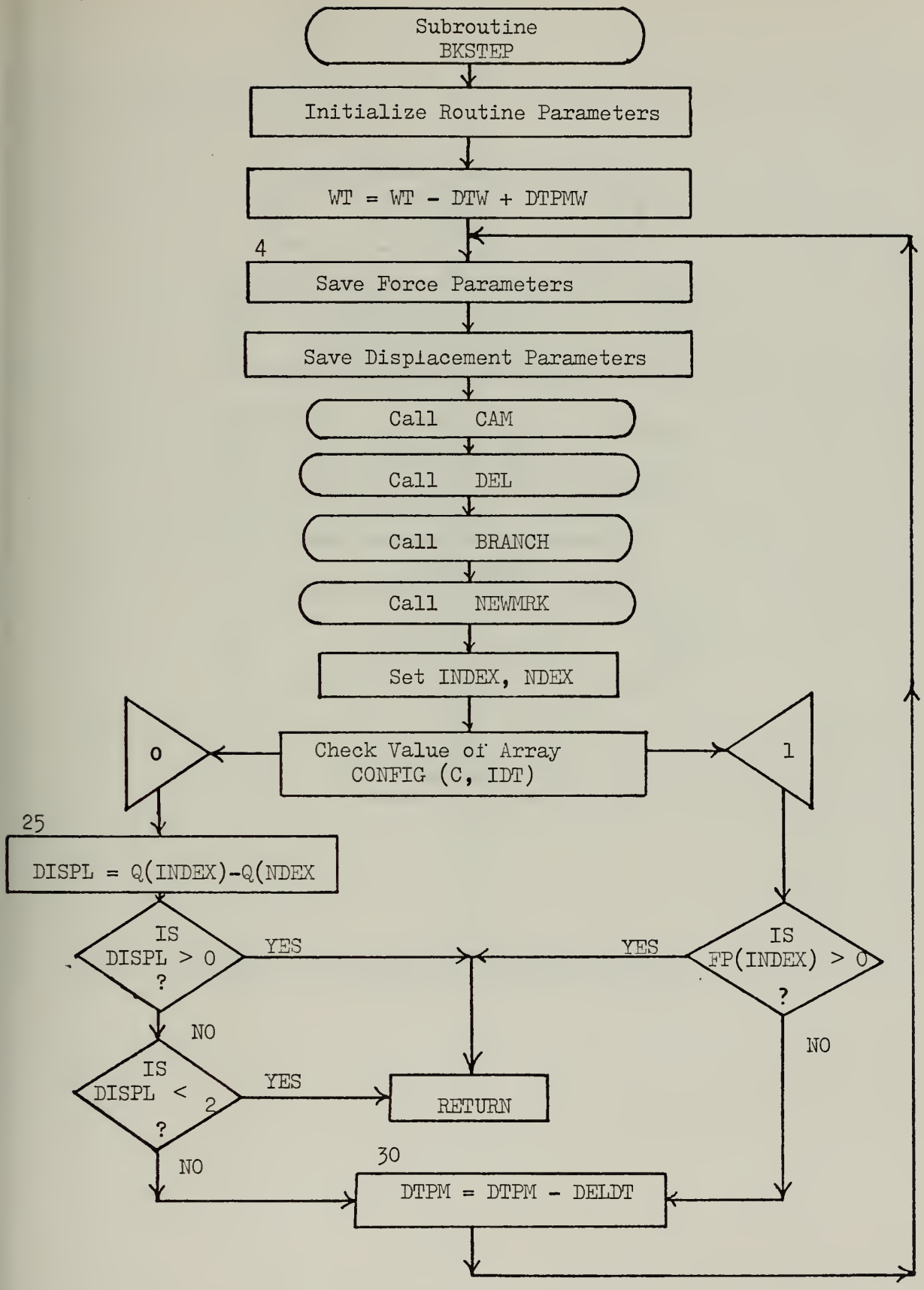


Figure 4.11 Subroutine BKSTEP Flow Diagram

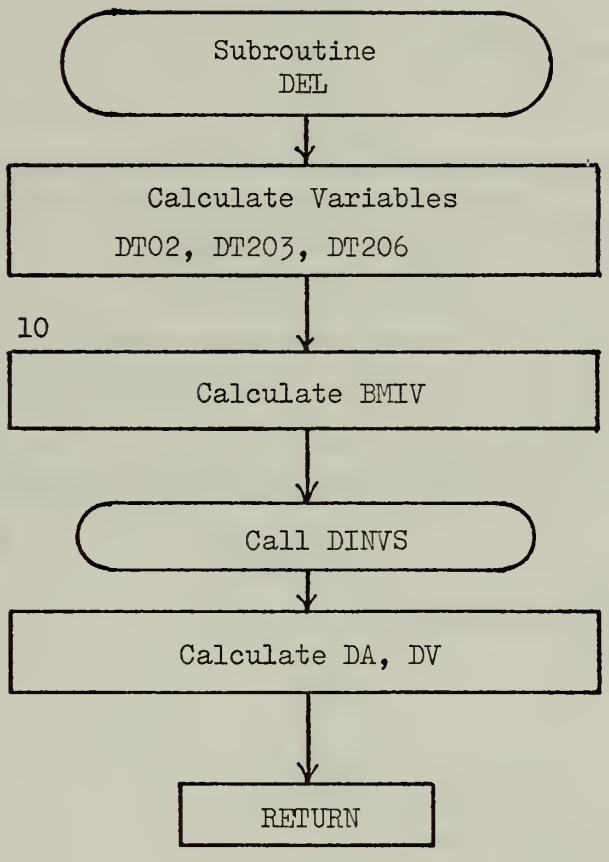


Figure 4.12 Subroutine DEL Flow Diagram

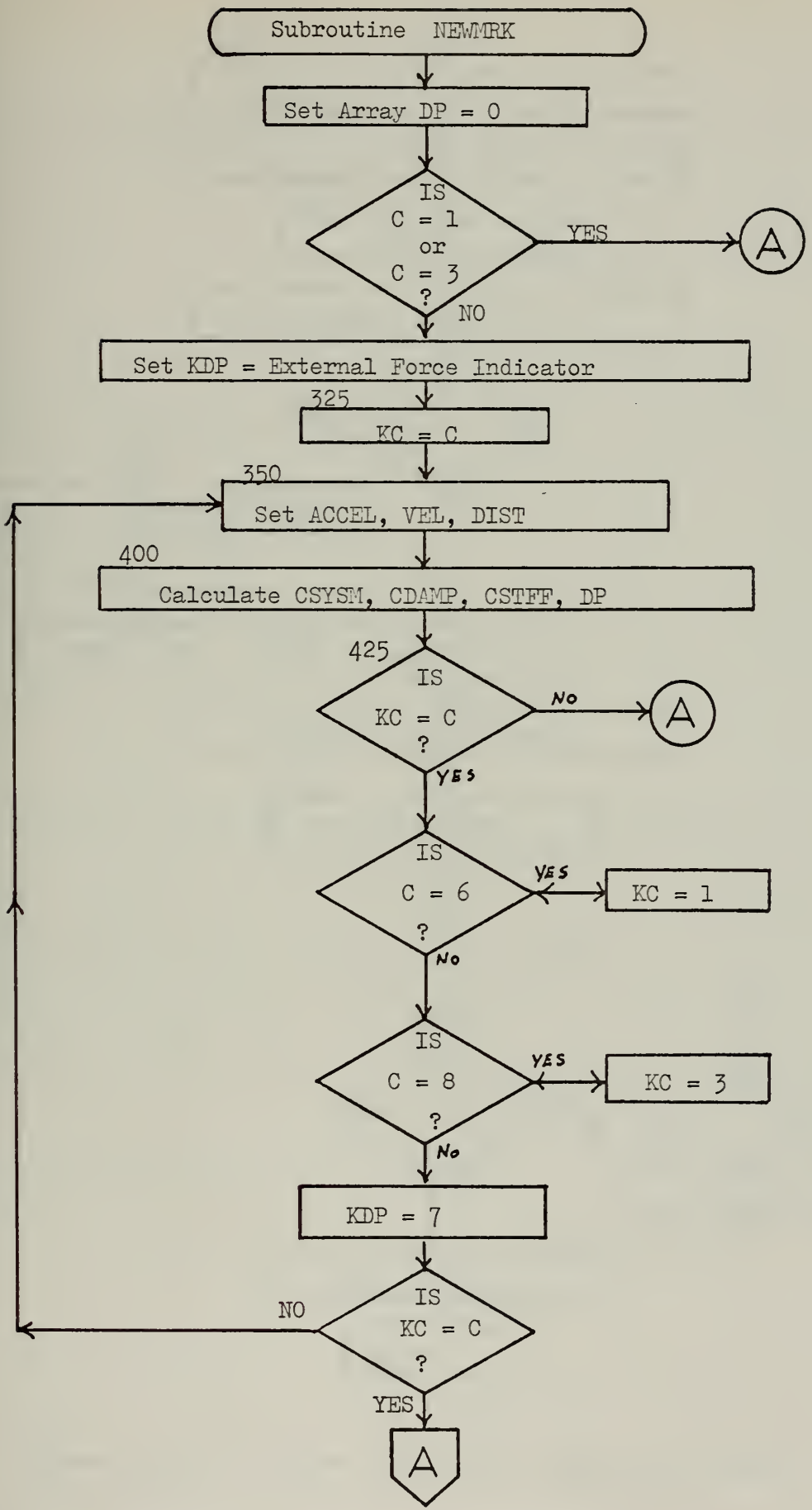


Figure 4.13-1 Subroutine NEWMRK Flow Diagram

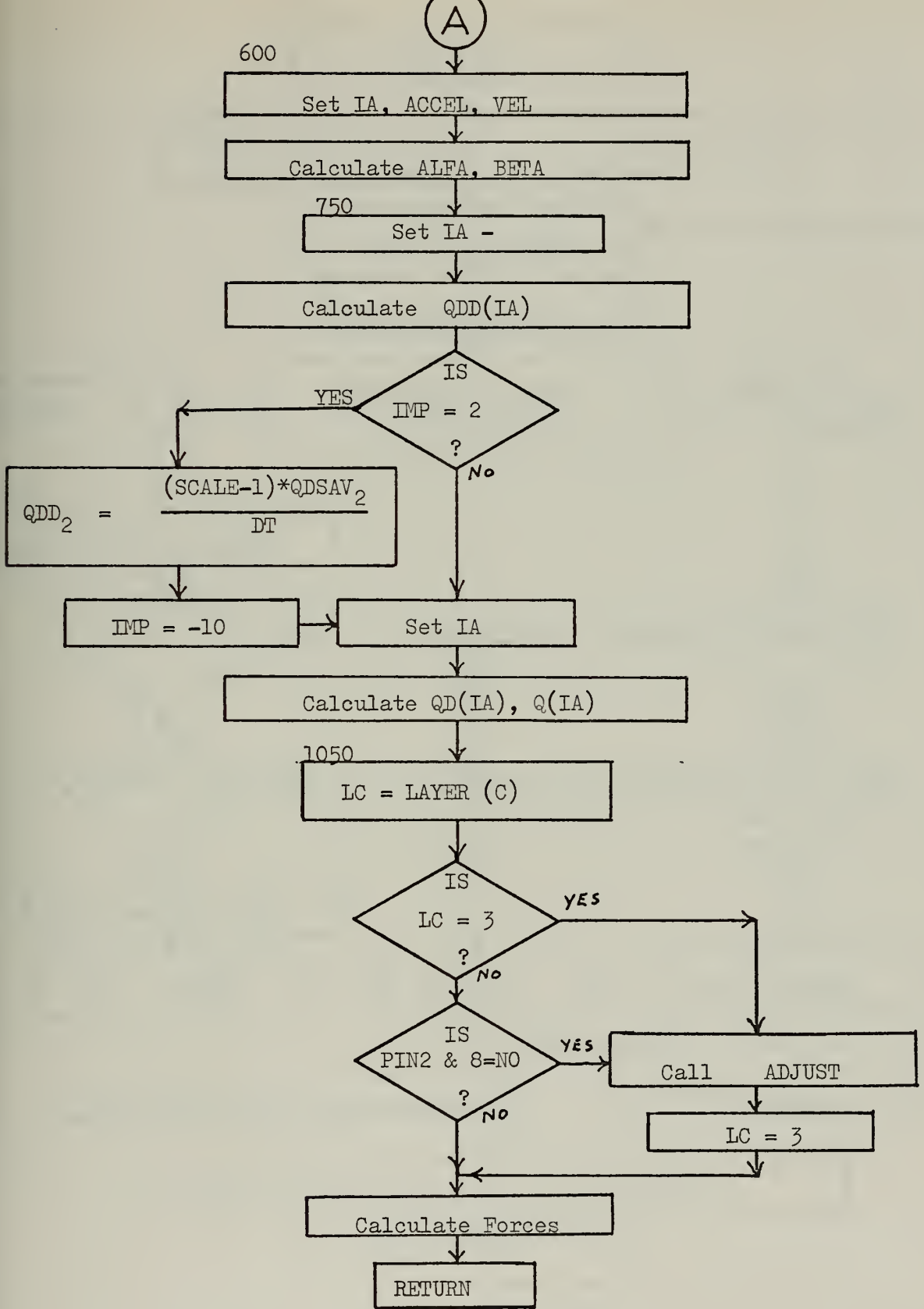


Figure 4.13-2 Continued - Subroutine NEWMRK Flow Diagram

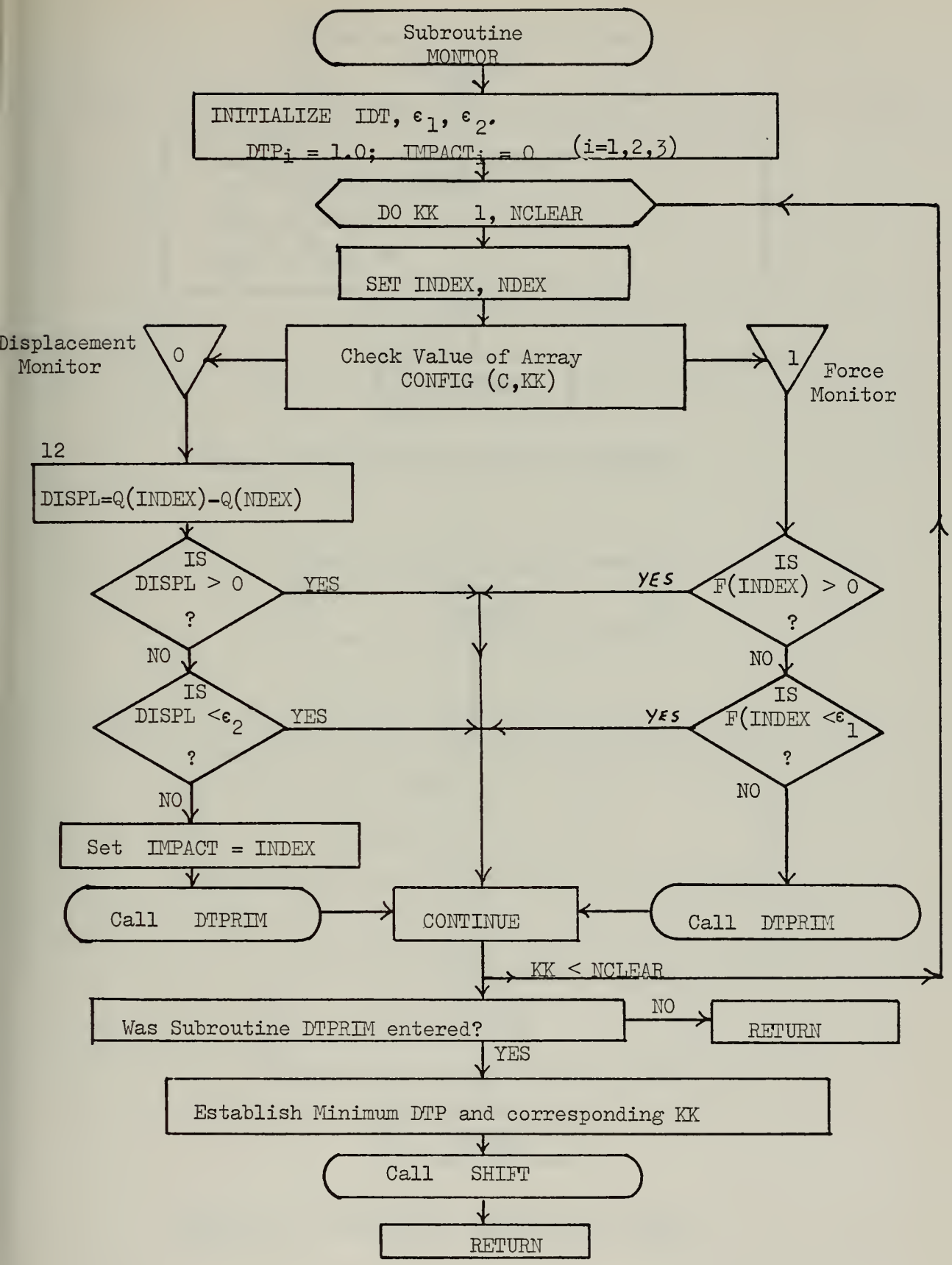


Figure 4.14 Subroutine MONTOR Flow Diagram

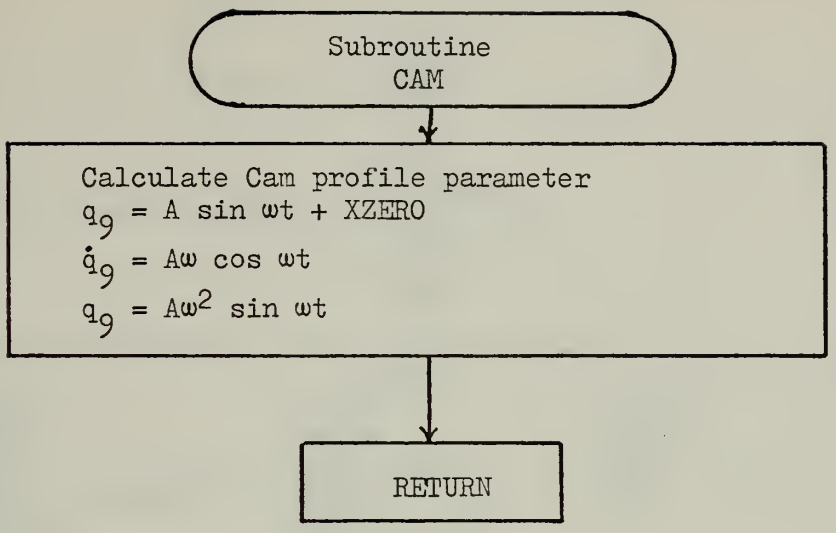


Figure 4.15 Subroutine CAM Flow Diagram

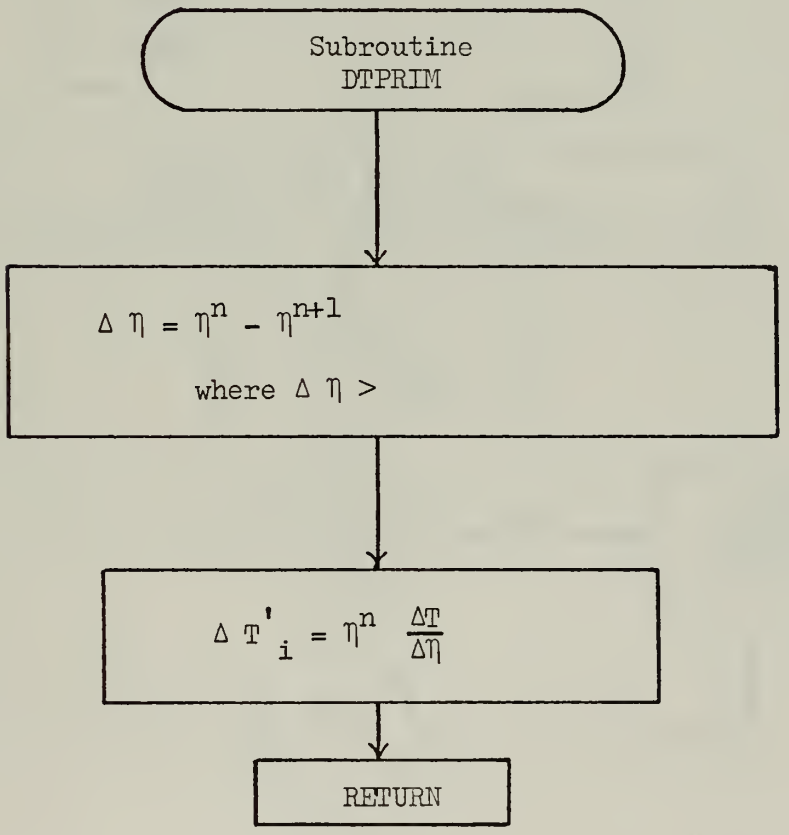


Figure 4.16 Subroutine DTPRIM Flow Diagram

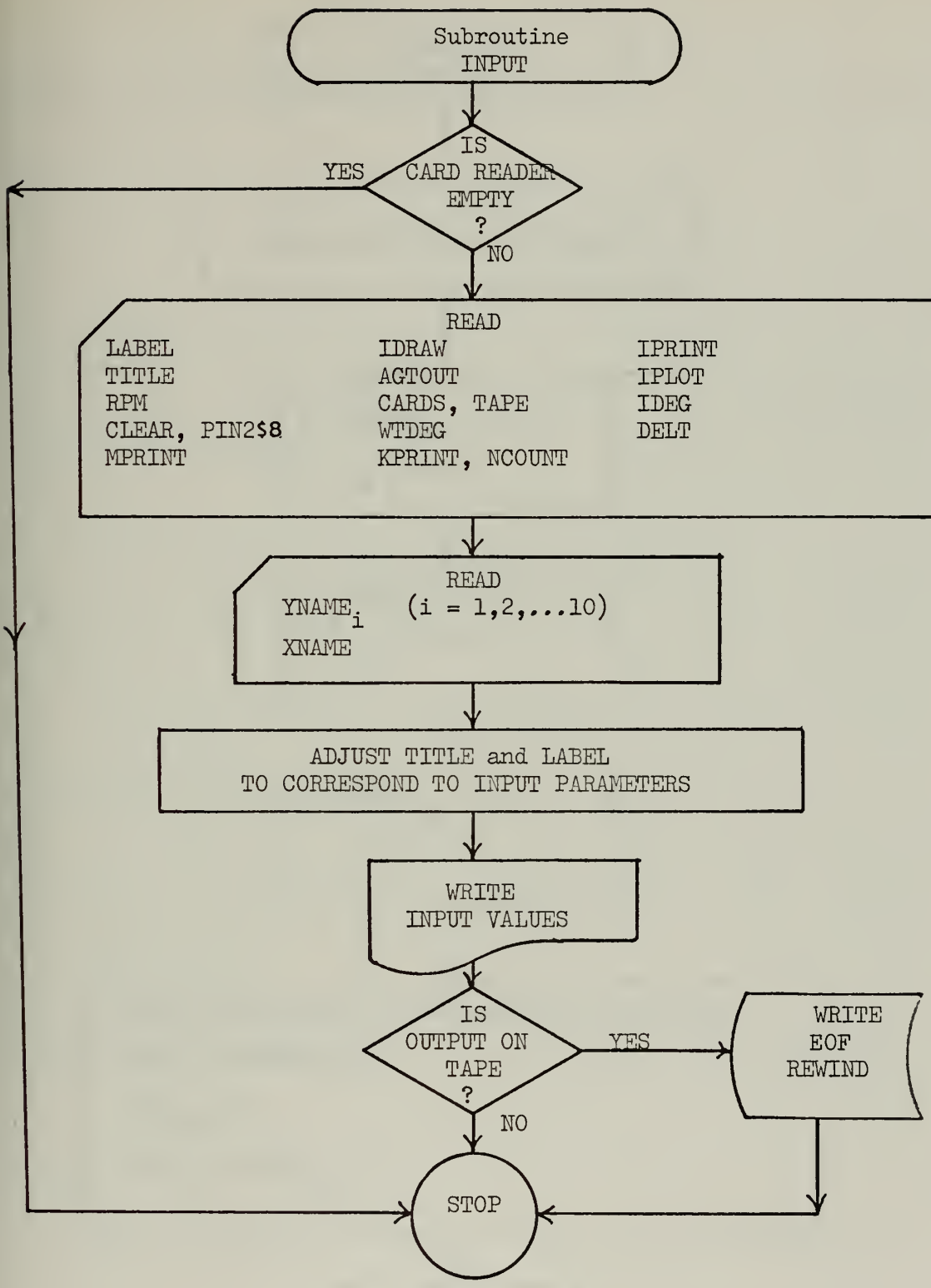


Figure 4.17 Subroutine INPUT Flow Diagram

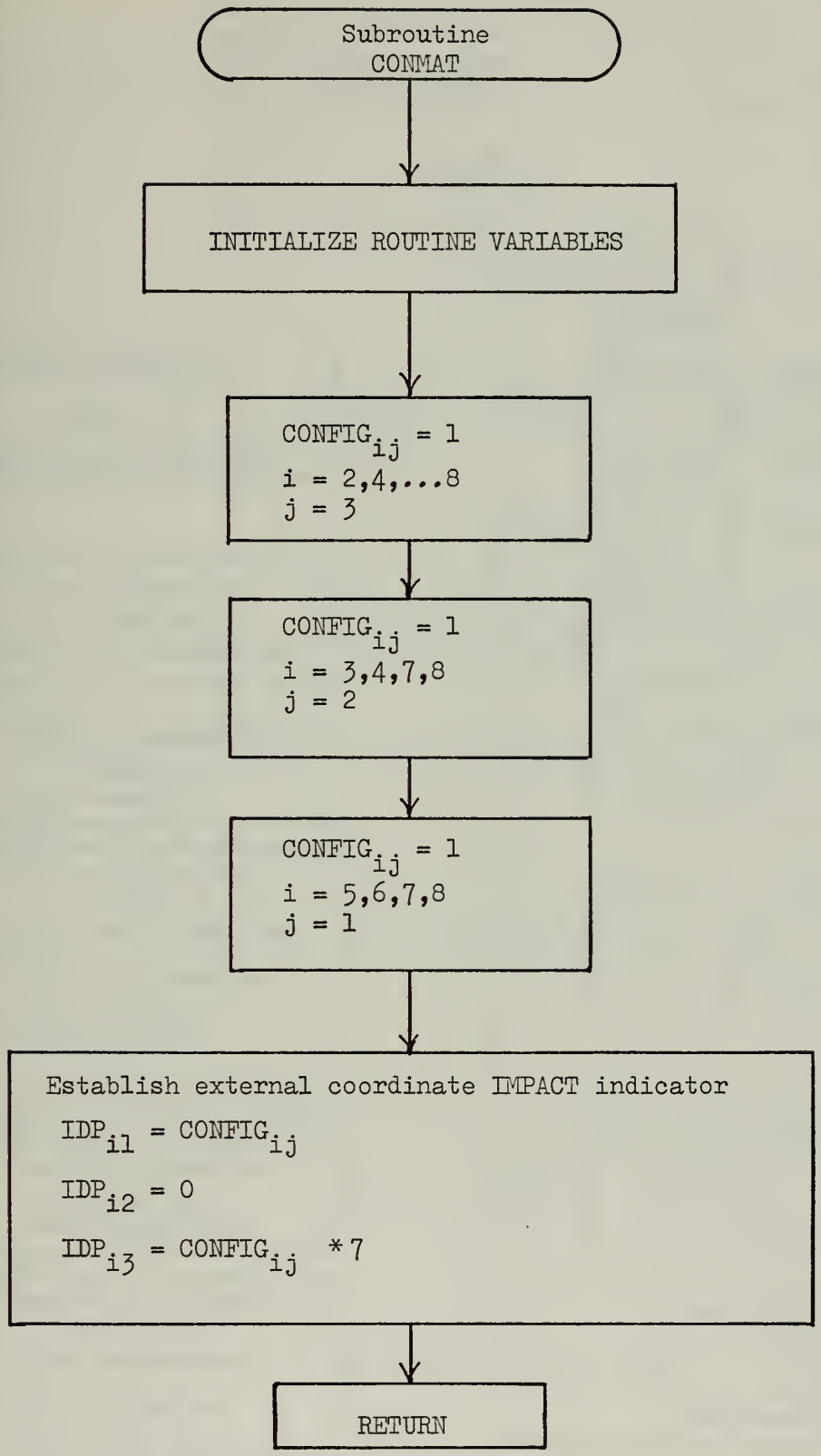


Figure 4.18 Subroutine CONMAT Flow Diagram

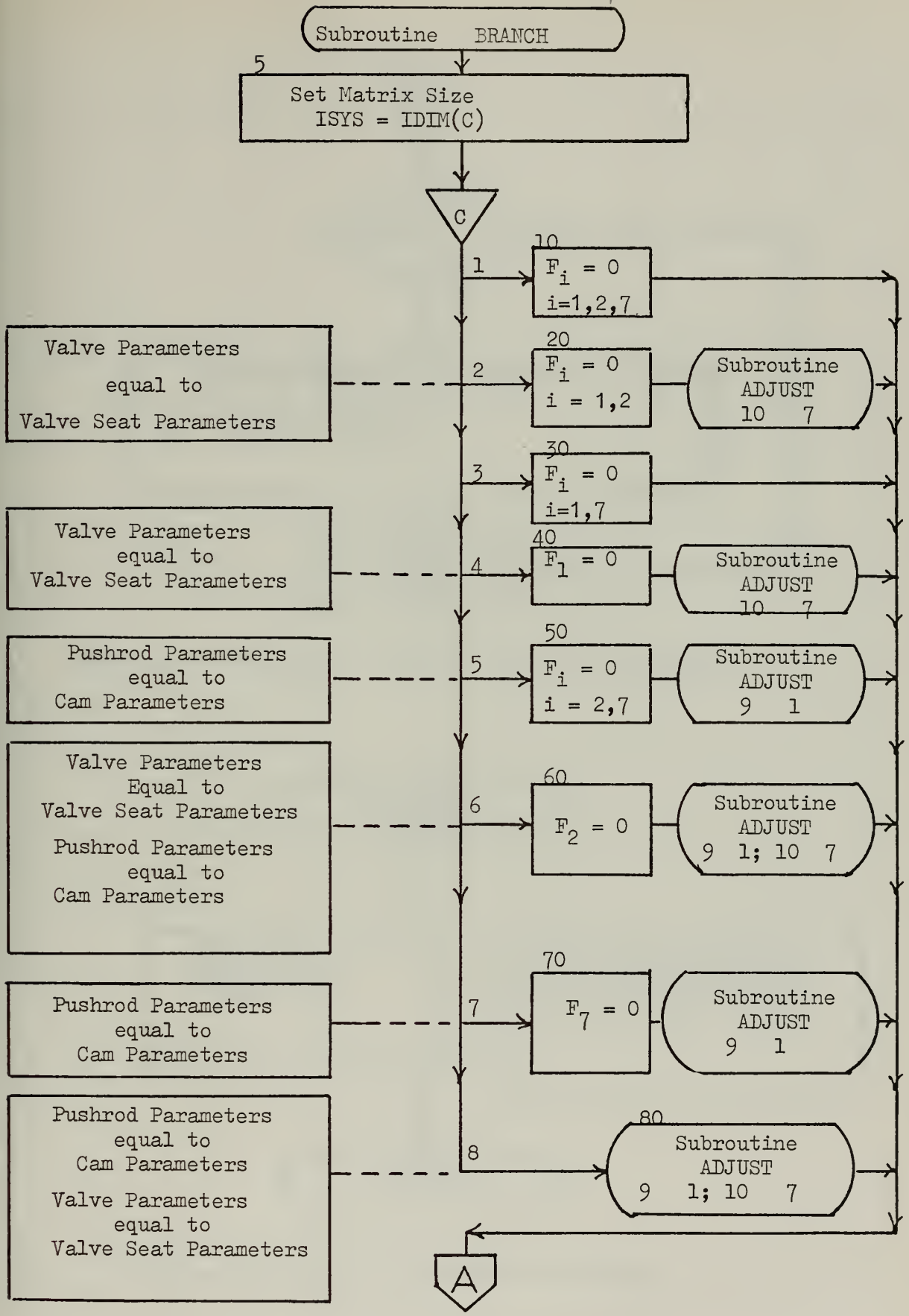


Figure 4.19 Subroutine BRANCH Flow Diagram

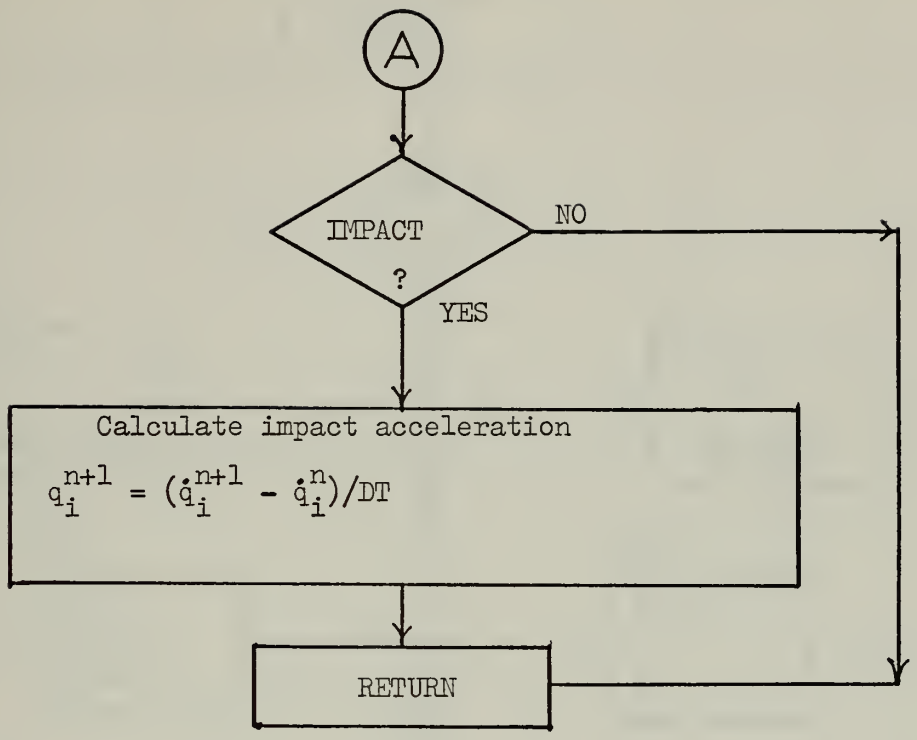


Figure 4.19 Continued - Subroutine BRANCH Flow Diagram

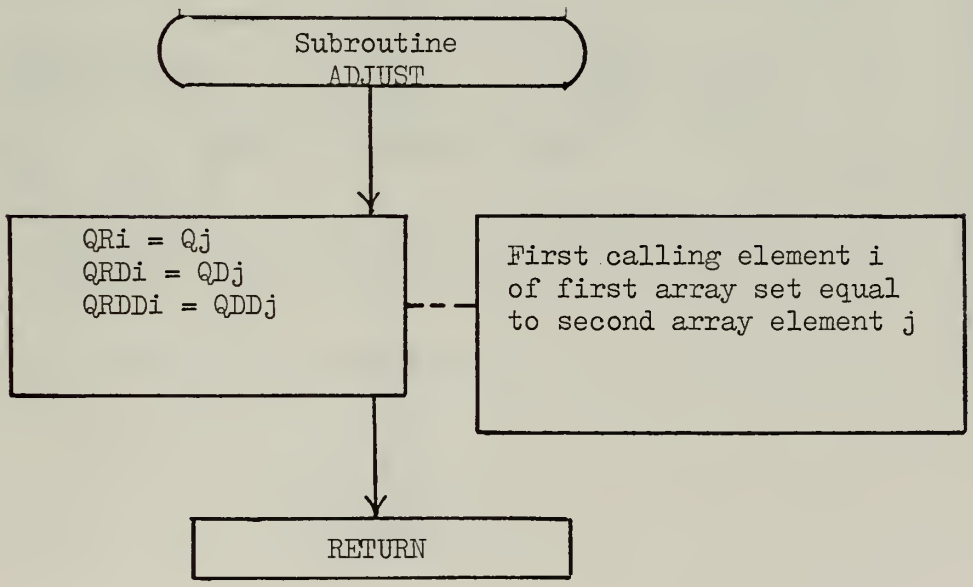


Figure 4.20 Subroutine ADJUST Flow Diagram

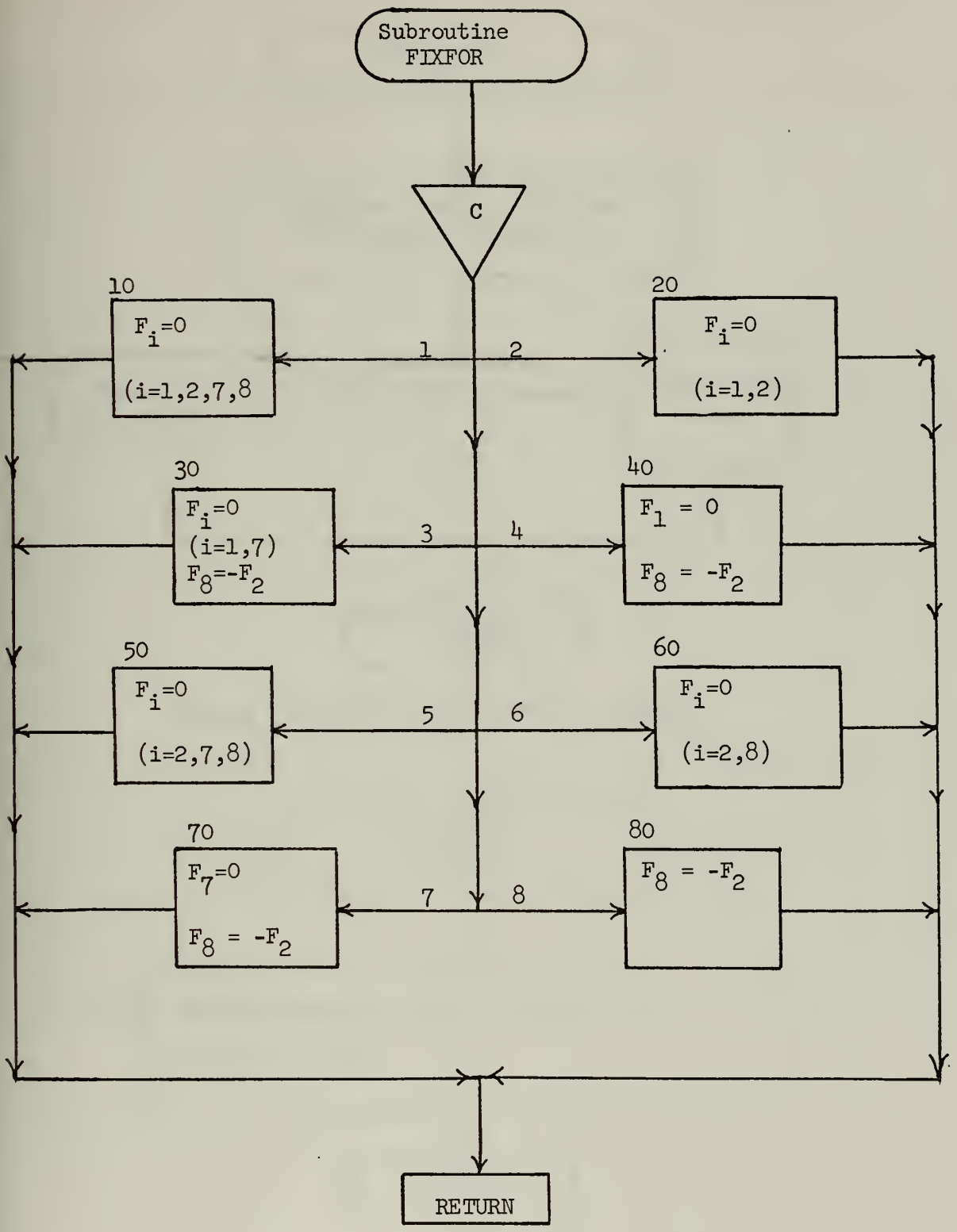


Figure 4.21 Subroutine FIXFOR Flow Diagram

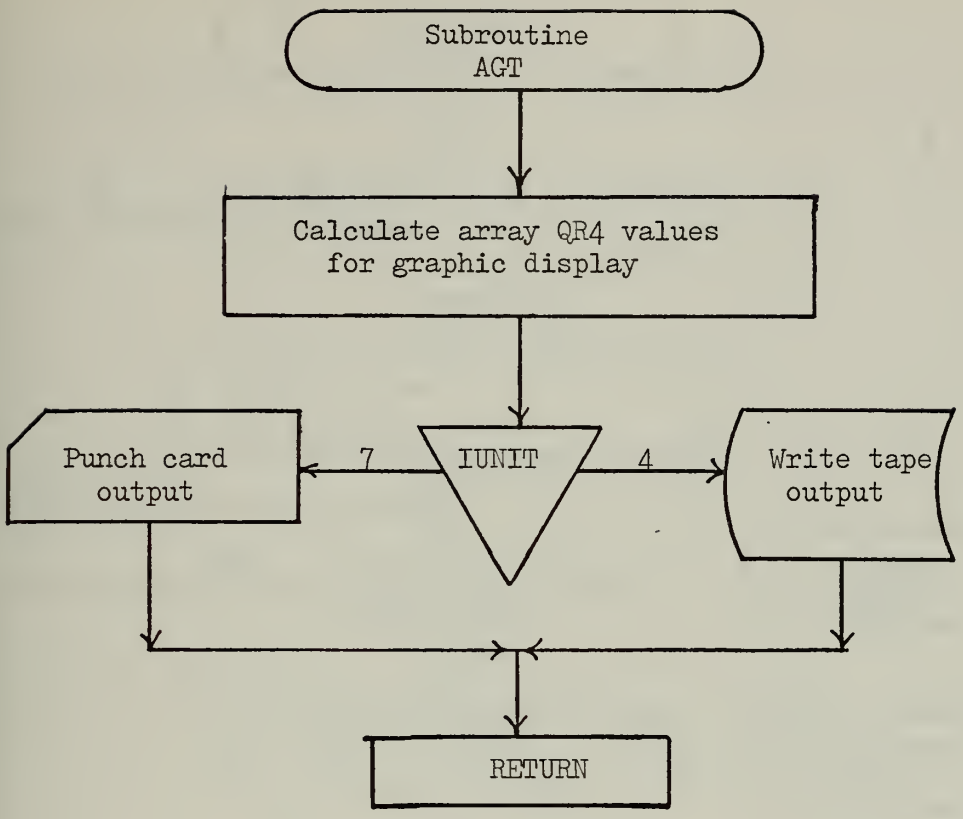


Figure 4.22 Subroutine AGT Flow Diagram

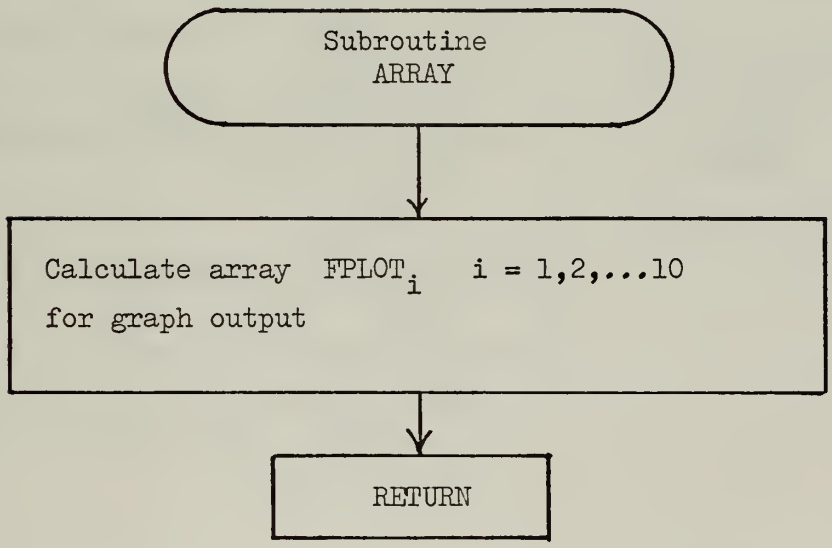


Figure 4.23 Subroutine ARRAY Flow Diagram

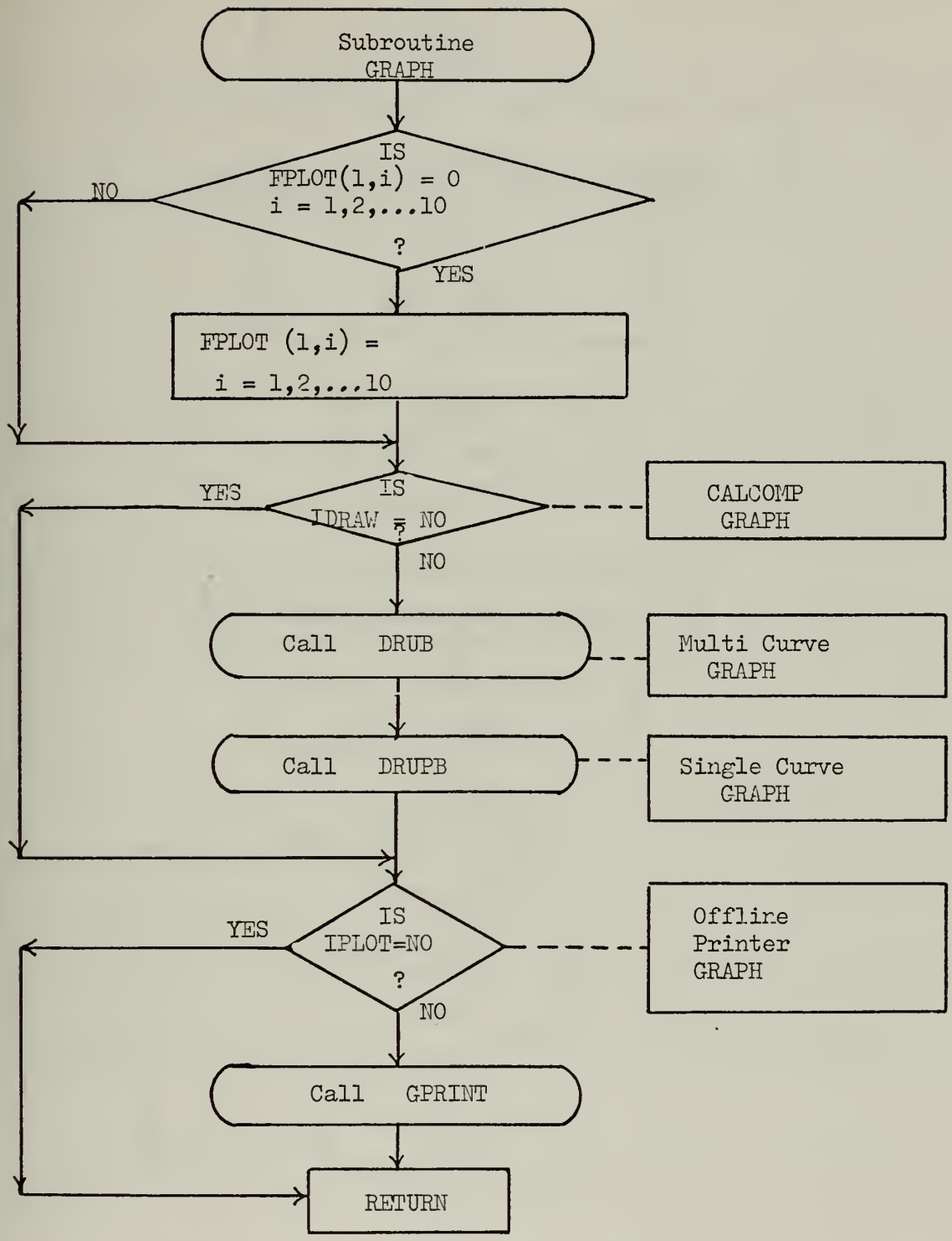


Figure 4.24 Subroutine GRAPH Flow Diagram

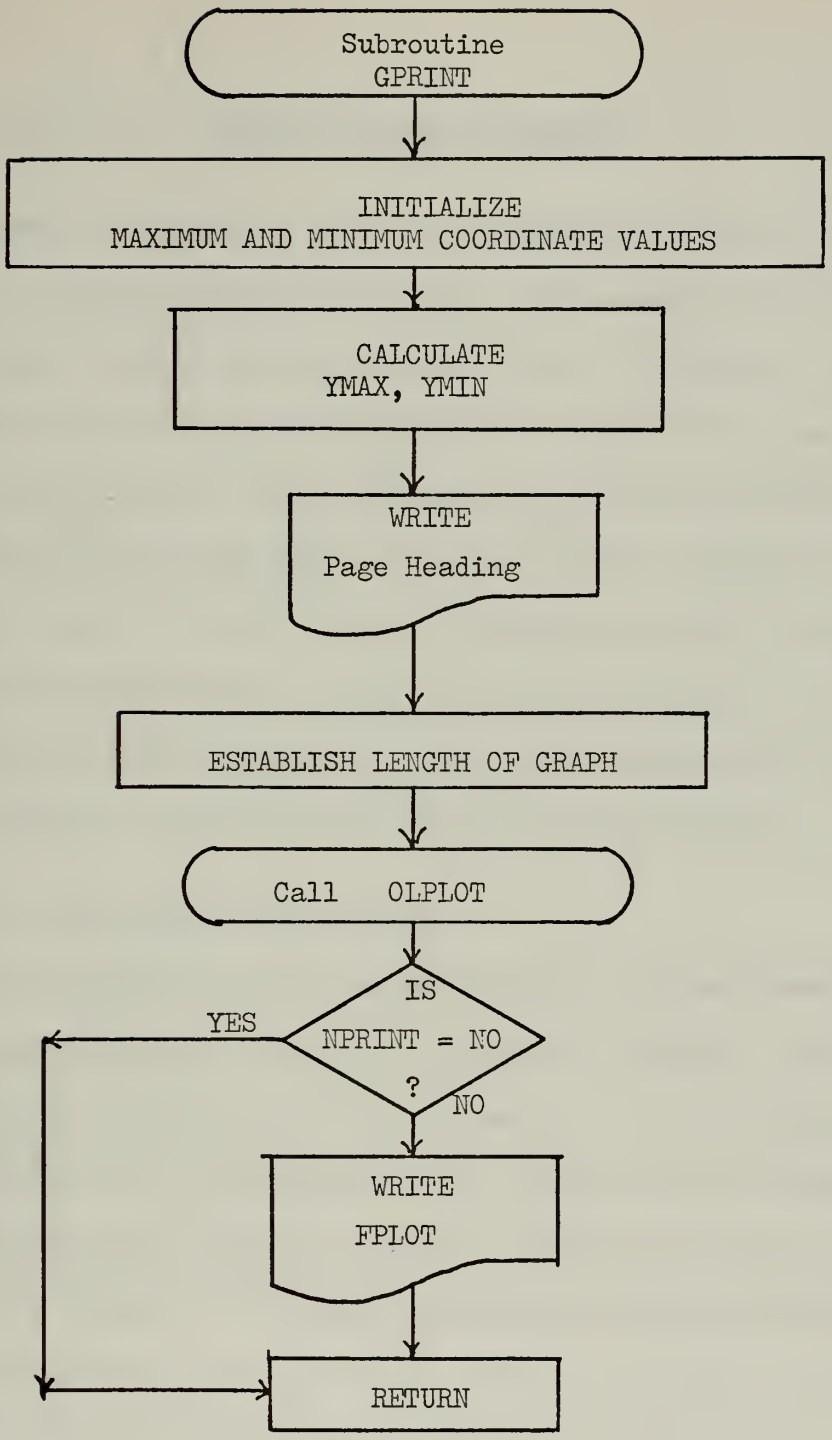


Figure 4.25 Subroutine GPRINT Flow Diagram

V. SDS-9300 COMPUTER PROGRAM

This computer program is coded in SDS FORTRAN IV, (Ref. 5-7), to run on a Scientific Data System Model 9300 computer interfaced with an ADAGE Graphics Display Terminal, Model 10 (AGT-10). This program provides the user the capability to observe the dynamic response of 360 degrees of cam rotation of the valve train assembly. The displacement data generated by the previously described program is the major input. Finite element techniques are used to reformulate the input displacement data to provide for the pictoral responses of bending and axial deformations. Due to the limited core storage of this computer, overlaying techniques have been employed.

A. METHOD OF ELASTICITY CALCULATIONS

As shown in Figure 2.4,the system consists of five elements. Three of these elements, (1,4, and 5) are axial members. The remaining two, (2 and 3) are bending members. Thus the elastic mode shapes for each of the elements as a functi on of the distance along the member will yield the required deformations. R. C. Winfrey, reference (1) Chapter V, has done considerable work in the formulation of the required mode shapes by finite element techniques. The mode shapes for the axial elements as a function of x are:

$$\Phi_1(x) = \frac{x}{L} \tag{5.1}$$

$$\Phi_2(x) = \frac{x}{L} - 1 \tag{5.2}$$

where L is the longitudinal dimension of the bar.

The mode shapes for the bending elements as a function of x are:

$$\Phi_1(x) = \frac{1}{L^3}(L^3 - 3x^2L + 2x^3) \tag{5.3}$$

$$\Phi_2(x) = \frac{1}{L^3}(3x^2L - 2x^3) \tag{5.4}$$

$$\Phi_3(x) = \frac{1}{L^2}(xL^2 - 2x^2L + x^3) \tag{5.4}$$

$$\Phi_4(x) = \frac{1}{L^2}(x^2L - x^3) \tag{5.6}$$

where L is the longitudinal dimension of the bar.

The system displacements are calculated by the IBM-360 program and sent as data to the SDS-9300. These displacements and the above mode shapes are superimposed to yield the required rigid body motion and elastic deformations.

B. PROGRAM STRUCTURE

1. General Description

The main program controls the program execution. The calling order is presented in Figure 5.1. The subroutines indicated by an asterick are supplied by the computer laboratory, and are used to manipulate and initialize data sent to the ADAGE Graphics Terminal. The SDS computer total core available for program execution, exclusive of the control and real time monitoring functions, is approximately 18 K bytes. Since the total program length greatly exceeds the core available, a program overlay technique consisting of storing only active subroutines during execution is employed. This achieves maximum use of the main core storage and allows the program to execute.

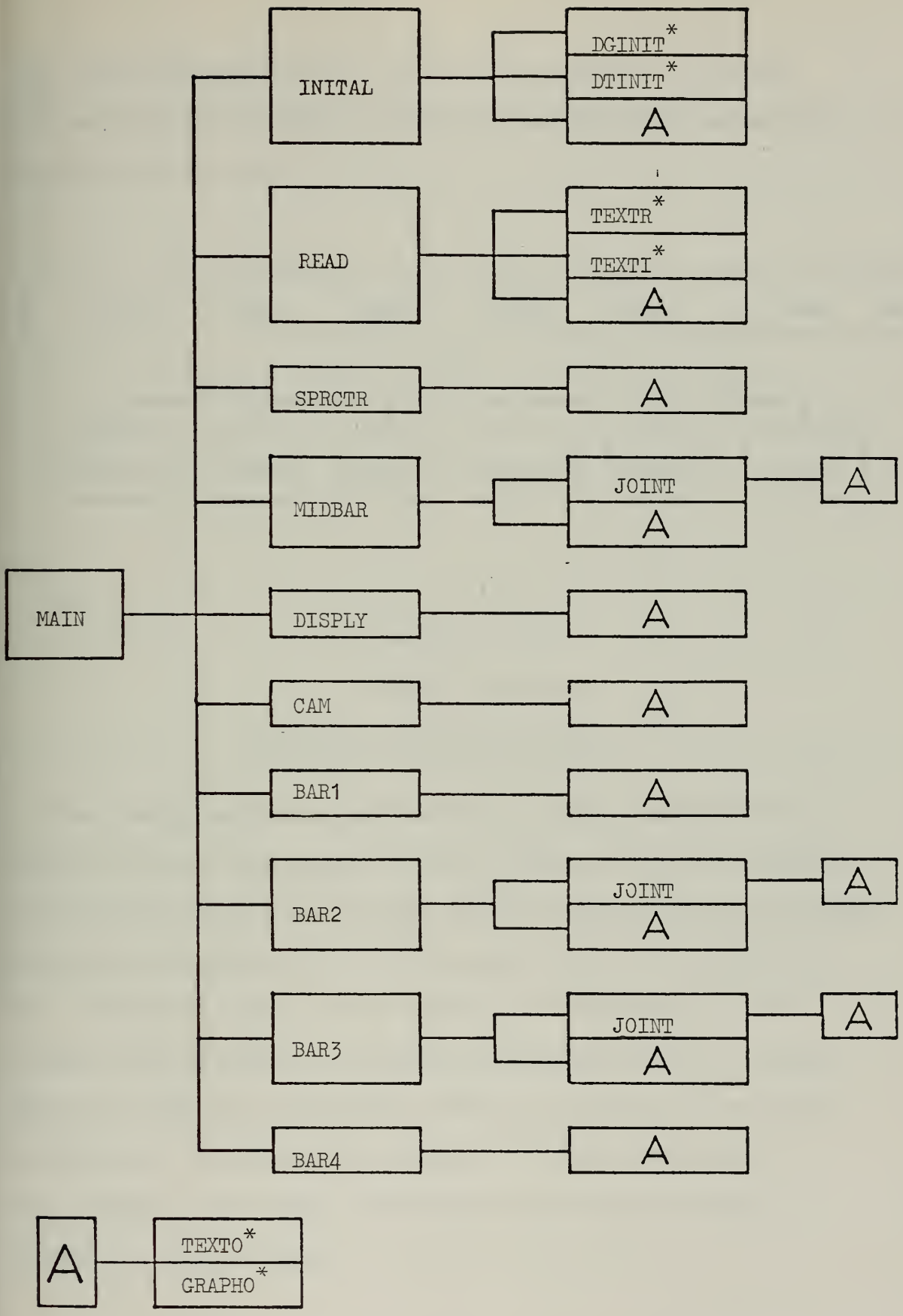
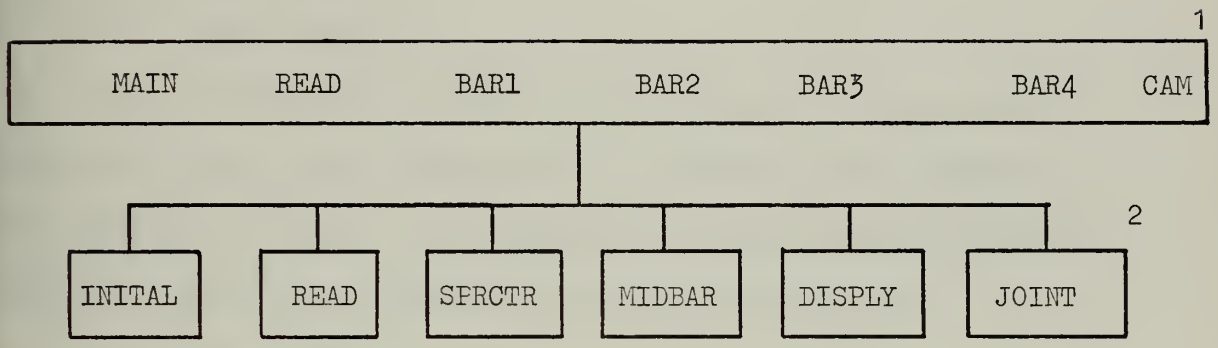


Figure 5.1 SDS-9300 Computer Program Structure

The overlay tree structure is depicted in Figure 5.2. Although necessary for this program, overlaying significately increases the program execution time.



1. Remains in core
2. Overlay structure

Figure 5.2 Overlay Structure

The bowing and thinning of the axial elements, as seen on the graphics display photographs, have been added as an aid in observing the deformations of these members. The mode shapes given by equations 5.1 and 5.2 are only valid for the elastic line of a one dimensional bar. However the small uniform extension and compression of the element were impossible to satisfactorily reproduce on the display. Thus the bowing and thinning were added as a function of the axial deformation. The thinner the bar, the more axial compression it has undergone. Conversely, the thicker the bar the more axial extension it has undergone.

2. Sense Lights

The SDS computer being a hands-on system, has several physical sense lights. When lit, logic within the program may alter computer instructions as desired.

a. Sense Light 1.

Activation of sense light one branches the execution to the head of the program. Execution then continues and variables are reinitialized as coded in the program. New data points may also be read in, displaying a different set of displacement data.

b. Sense Light 2.

During program execution this sense light indicates that the display will utilize ADAGE Graphics Terminal, number two. When not lit, the SDS computer is interfaced with the AGT unit number one.

c. Sense Light 4.

This sense light branches the program to a convenient point to reinitialize the originally coded program parameters. This is accomplished by activation of the SDS control console teletype from which the user may input any program variables that appear in the namelist statement.

d. Sense Light 6.

Activation of sense light six calls the subroutine TEXTR for each cam rotation increment. This enables the motion of the display to be halted for further study at any point of interest in cam rotation. Depression of the return key on the AGT terminal will advance the display to the next display of cam rotation.

C. MAIN PROGRAM

The main program initializes parameters, establishes the data arrays and contains the calculation loop. Prior to the execution of the program the desired sense lights should be activated. The program is halted almost immediately after execution by an INPUT statement. This statement allows the user to have positive control over assignment of the AGT unit. The designation of the wrong unit at this point will case a core image failure. The program then must be reloaded. Therefore at this point the 9300 teletype control console should be checked to insure the correct unit is listed in the message to the user. To proceed with the program execution a "*" must be typed on the control console followed by the carriage return key.

Subroutines are called to display the fixed elements of the model. The two arrays that reproduce the circular cam are pre-calculated. Next the frequency ratio is calculated and displayed. The cycle loop is then entered where subroutines are called to display the movable elements. This loop is incremented by a specified amount of cam rotation until 360 degrees of rotation has been reached. At this point the cycle is repeated. For each cam increment, the sense lights are tested.

D. SUBROUTINES

The function of each of the subroutines and a description of their execution are included. Each subroutine is listed in its entirety in the SDS-9300 Computer Program Listing.

1. Subroutine INITAL

This subroutine initializes the text and graphics directory arrays, DTINIT and DGINIT, respectively. The text response, TEXTR is initialized to block number one at display location 39, 46. The title display is encoded and presented on the AGT. The graphic data blocks are initialized to zero, assigned the appropriate first word header (IHEAD), and then assigned sequence numbers in DGINIT for later use.

2. Subroutine READ

This subroutine reads the title and label for the program and prints them on the offline printer. The program parameters are read, (XZERO, AMP, RPM, WN, ISEAT, and PIN28) and also printed for reference. The user is then questioned from the AGT display, Photo 5.1.

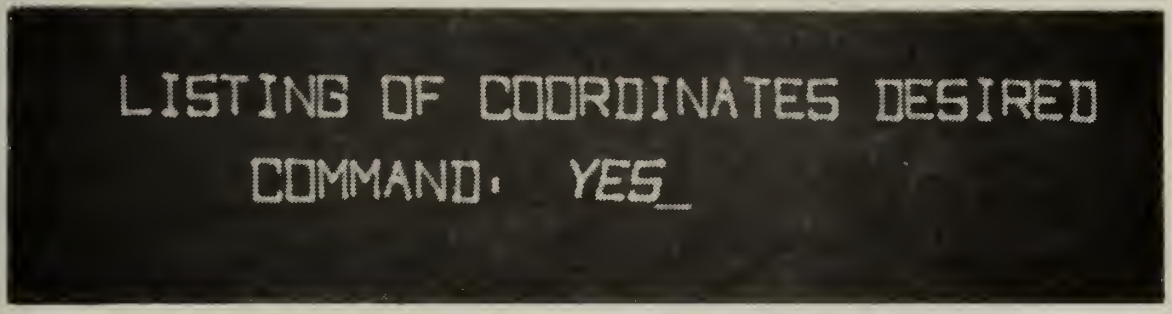
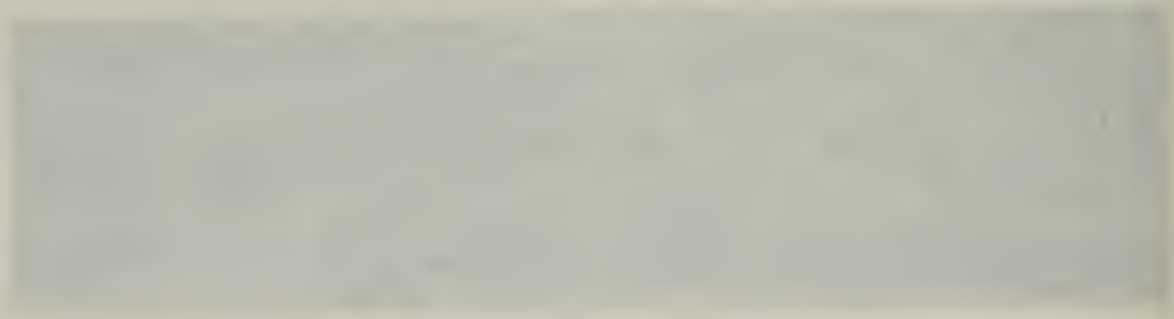


Photo 5.1 AGT QUESTION

An affirmative response will list the IBM-360 displacement data on the offline printer. The response is entered via the graphics terminal.

The displacement data is next read from magnetic tape or punched cards, depending on the control specification at the time the program was loaded. The array parameters read are, Q1 through Q9, OMEGA, and CONFIG. The Q's are as defined in the IBM program but



modified by the amount XZERO. OMEGA is the amount of revolution of the cam in radians. CONFIG is the corresponding configuration number. Next the displacements are printed, if desired. Finally the title screen is nulled and control is returned to the main program.

3. Subroutine SPRCTR

This subroutine is only called once for a given problem. The display for the rigid portion of the spring is calculated and displayed. The valve seat position and geometry is calculated. The parameter ISEAT is then checked to determine whether the problem considers contact at the valve seat. For those problems with no contact, the valve seat location is adjusted to better picture the position. Finally the valve seat is displayed and control returns to the main program.

4. Subroutine MIDBAR

This subroutine is called once. Subroutine MIDBAR calculates and displays the fixed pivot point.

5. Subroutine DISPLY

This subroutine is called once during each cam increment. The function of this routine is to display the text for the system configurations.

6. Subroutine CAM

Subroutine CAM is called once during each cam increment. This routine calculates the cam position, given the cam rotation (OMEGA) and displacement of the top of the cam (q_9).

7. Subroutine BAR1

This subroutine is called once during each cam increment. Coordinates q_1 and q_8 are used to calculate the position of the pushrod. Equations 5.1 and 5.2 calculate the deformations. The pushrod is then displayed on the AGT.

8. Subroutine BAR2

This subroutine is called once during each cam increment. Coordinates q_2, q_3, and q_6, and equations 5.3, 5.4, and 5.5 are used in the calculations of position, geometry, and deformations of the left rocker arm. The parameter PIN28 is checked to determine whether the pin should be displayed at clearance two. The left rocker arm and pin, if required, are displayed on the AGT.

9. Subroutine BAR3

This subroutine is called once during each cam increment. Coordinates q_4, q_5, and q_6, and equations 5.3, 5.4, and 5.5 are used in the calculation of position, geometry, and deformations of the right rocker arm. Calculation of the position and image of the rocker arm- valve stem- valve spring joint pin is accomplished by subroutine JOINT. The right rocker arm and pin are then displayed on the AGT.

10. Subroutine BAR4

This subroutine is called once during each cam increment. Coordinates q_4 and q_7 are used to calculate the position of the valve stem. Equations 5.1 and 5.2 calculate the deformations. The valve-valve stem is then displayed on the AGT.

11. Subroutine JOINT

This subroutine is called once for the right rocker arm pin and, if required, once for the left rocker arm pin, during each cam increment. The pins' position and image are calculated and displayed on the AGT.

VI. NUMERICAL RESULTS

The precalculated system matrices for the physical properties assumed in chapter 2, are presented in this chapter. Numerical examples have been chosen for their interest and for comparison with one another. The relationship between examples is indicated in Figure 6.26. Example results are presented both as CALCOMP graphs and/or AGT display photos. Photo 6.1 is the title page from the graphics terminal display.

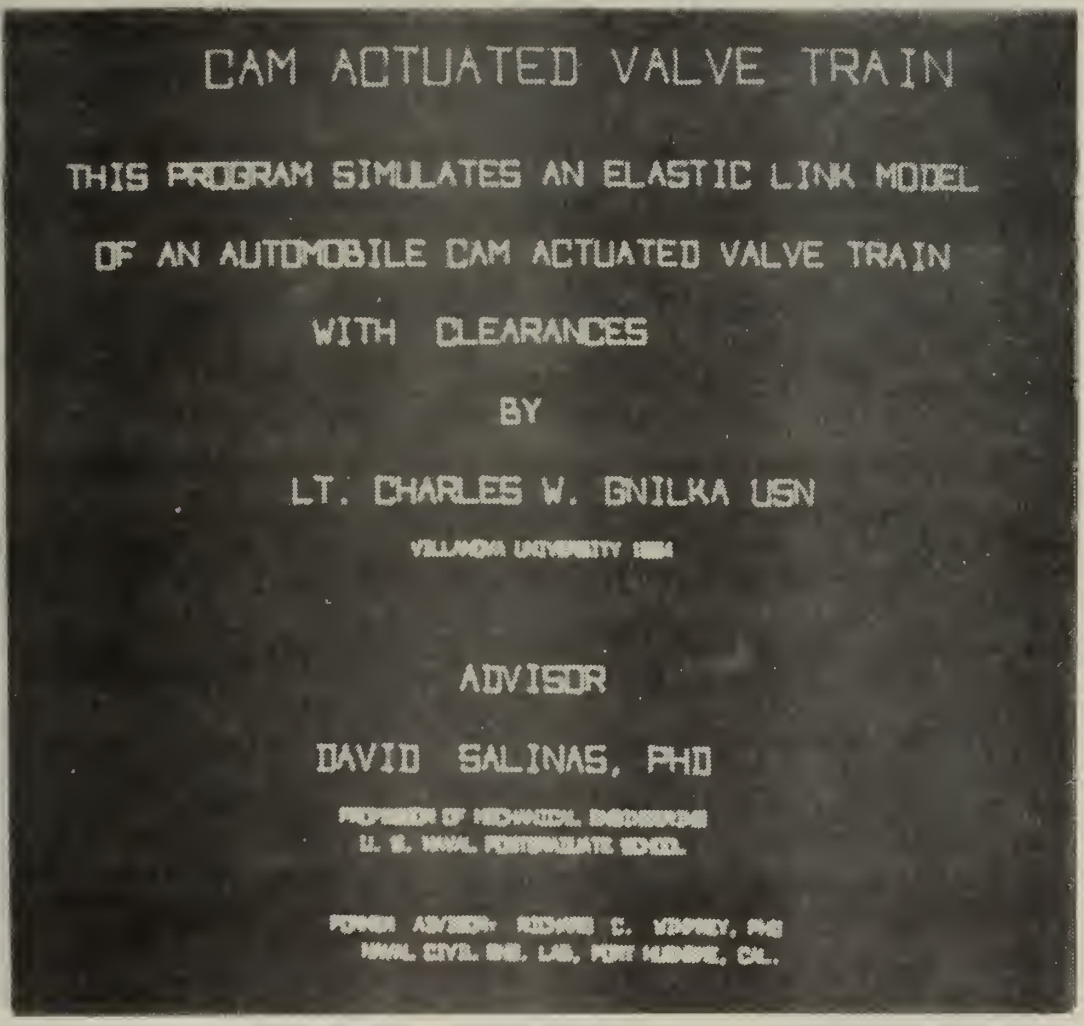


Photo 6.1 AGT Title Page

A. MODE SHAPES AND NATURAL FREQUENCIES

The mode shapes and natural frequencies presented in Figure 6.1 result from the eigenvalue problem for the full eight coordinate system. Figure 6.2 shows the values resulting from the seven coordinate reduced system, for contact at the rocker.

NATURAL FREQUENCIES ω_n (EIGENVALUES) x 10^3

0.0	63.6	638.7	0.886	263.8	1371.1	149.8	77.86

MODE SHAPES (EIGENVECTORS) IN COLUMNS [Φ]

46.3	0.0	0.0	0.0	0.0	0.0	0.0	-80.2
0.0	115.0	-109.5	-37.1	-57.2	-172.7	33.3	0.0
0.0	-131.3	581.0	37.1	149.1	1538.0	-56.0	0.0
0.0	21.5	-34.2	55.6	60.9	18.7	42.5	0.0
0.0	58.7	-499.4	37.0	347.7	376.9	-29.8	0.0
0.0	-70.9	-340.0	37.1	-146.7	381.4	24.6	0.0
0.0	-35.0	-18.9	-55.6	52.8	9.6	120.0	0.0
46.3	0.0	0.0	0.0	0.0	0.0	0.0	80.2

Figure 6.1 FULL SYSTEM MODE SHAPES AND NATURAL FREQ.

NATURAL FREQUENCIES ω_n (EIGENVALUES) x 10^3

0.691	73.6	521.9	25.9	247.1	1070.2	146.7

MODE SHAPES (EIGENVECTORS) IN COLUMNS [Φ]

28.96	-69.26	15.64	45.72	11.22	12.01	-8.39
28.95	64.03	-30.77	20.91	-20.84	-23.92	13.67
-28.95	-70.49	503.13	-30.45	136.63	799.47	-42.66
-43.37	9.09	-34.11	39.89	61.27	25.02	38.35
-28.90	32.45	-427.34	39.72	313.46	471.17	-45.62
-28.93	-42.34	-215.68	-1.53	-164.75	436.79	44.23
43.37	-18.08	-19.75	-42.97	57.06	12.96	118.61

Figure 6.2 REDUCED SYSTEM MODE SHAPES AND NATURAL FREQ.

B. PRE-CALCULATED SYSTEM MATRICES

The remaining system matrices are presented and grouped according to their layer (or configuration) number. The mass, stiffness, and damping matrices for layer one are unaltered and directly correspond to the full eight coordinate system eigenvalue problem. The mass, stiffness, and damping matrices in layer three are unaltered and directly correspond to the reduced seven coordinate system eigenvalue problem.

The pre-calculated matrices COLM, COLC, and COLK located in layers one and three are associated with the calculations for configurations six and eight respectively. Thus, these matrices are not listed in their correct program layer, but with the correct configuration with which they are used.

The order of presentation within each layer is: (1) Mass, (2) Damping, (3) Stiffness, (4) COLM, (5) COLC, (6) COLK, (7) BMIV, (8) DA, and (9) DV.

CONFIGURATION AND MATRIX LAYER = 1

MATRICES ARE 8X8

--- SYSM ---

1.55D-04	0.0	0.0	0.0	0.0	0.0	0.0	7.77D-05
0.0	7.70D-05	1.09D-05	0.0	0.0	-6.42D-06	0.0	0.0
0.0	1.09D-05	1.97D-06	0.0	0.0	-1.48D-06	0.0	0.0
0.0	0.0	0.0	2.01D-04	-2.44D-05	1.44D-05	-2.59D-05	0.0
0.0	0.0	0.0	-2.44D-05	6.66D-06	-5.00D-06	0.0	0.0
0.0	-6.42D-06	-1.48D-06	1.44D-05	-5.00D-06	8.64D-06	0.0	0.0
0.0	0.0	0.0	-2.59D-05	0.0	0.0	5.18D-05	0.0
7.77D-05	0.0	0.0	0.0	0.0	0.0	0.0	1.55D-04

--- DAMP ---

6.05D-01	0.0	0.0	0.0	0.0	0.0	0.0	-6.05D-01
0.0	1.32D 00	2.93D-01	5.54D-01	-1.69D-01	2.49D-01	-7.00D-02	0.0
0.0	2.93D-01	1.42D-01	1.00D-01	-3.70D-02	2.01D-02	-1.01D-02	0.0
0.0	5.54D-01	1.00D-01	1.51D 00	-3.36D-01	-5.39D-02	9.12D-01	0.0
0.0	-1.69D-01	-3.70D-02	-3.36D-01	2.71D-01	-6.93D-02	-1.09D-01	0.0
0.0	2.49D-01	2.01D-02	-5.39D-02	-6.93D-02	4.69D-01	5.66D-02	0.0
0.0	-7.00D-02	-1.01D-02	9.12D-01	-1.09D-01	5.66D-02	9.31D-01	0.0
-6.05D-01	0.0	0.0	0.0	0.0	0.0	0.0	6.05D-01

--- STF ---

2.36D 05	0.0	0.0	0.0	0.0	0.0	0.0	-2.36D 05
0.0	2.29D 06	1.15D 06	0.0	0.0	1.15D 06	0.0	0.0
0.0	1.15D 06	7.63D 05	0.0	0.0	3.82D 05	0.0	0.0
0.0	0.0	0.0	1.39D 06	-5.09D 05	-5.09D 05	7.07D 05	0.0
0.0	0.0	0.0	-5.09D 05	5.09D 05	2.54D 05	0.0	0.0
0.0	1.15D 06	3.82D 05	-5.09D 05	2.54D 05	1.27D 06	0.0	0.0
0.0	0.0	0.0	7.07D 05	0.0	0.0	7.07D 05	0.0
-2.36D 05	0.0	0.0	0.0	0.0	0.0	0.0	2.36D 05

Figure 6.3 CONFIGURATION I - Mass, Damping, and Stiffness

CONFIGURATION AND MATRIX LAYER = 1

MATRICES ARE 8X8

- (BMIV) -

```
 8.52D 03   0.0          0.0          0.0          0.0          0.0          0.0         -4.23D 03
 0.0         4.99D 04   -2.66D 05   -4.90D 02   -1.14D 04   -1.31D 04   -2.34D 02    0.0
 0.0        -2.66D 05    1.97D 06    7.95D 03    1.89D 05    2.18D 05    3.94D 03    0.0
 0.0        -4.90D 02    7.95D 03    1.02D 04    4.24D 04    8.16D 03    4.96D 03    0.0
 0.0        -1.14D 04    1.89D 05    4.24D 04    4.40D 05    1.97D 05    2.09D 04    0.0
 0.0        -1.31D 04    2.18D 05    8.16D 03    1.97D 05    2.30D 05    4.04D 03    0.0
 0.0        -2.34D 02    3.94D 03    4.96D 03    2.09D 04    4.04D 03    2.15D 04    0.0
-4.23D 03   0.0          0.0          0.0          0.0          0.0          0.0         8.52D 03
```

- (DA) -

```
 7.72D 03   0.0          0.0          0.0          0.0          0.0          0.0         -7.72D 03
 0.0        -1.35D 04   -2.31D 04    4.56D 03   -6.00D 02    1.73D 03   -9.68D 02    0.0
 0.0         2.53D 05    2.01D 05   -8.87D 03    4.95D 03    6.25D 04    1.29D 03    0.0
 0.0         1.81D 03    5.51D 02    5.75D 03    6.77D 03    6.55D 02    9.68D 03    0.0
 0.0         3.66D 04    1.52D 04   -6.27D 04    8.42D 04    6.15D 04    2.01D 04    0.0
 0.0         7.47D 04    2.53D 04   -4.78D 04    2.83D 04    9.52D 04    1.49D 03    0.0
 0.0        -4.46D 02    7.92D 01    2.01D 04    1.26D 03    1.42D 03    2.25D 04    0.0
-7.72D 03   0.0          0.0          0.0          0.0          0.0          0.0         7.72D 03
```

- (DV) -

```
 3.00D 09   0.0          0.0          0.0          0.0          0.0          0.0         -3.00D 09
 0.0        -2.05D 11   -1.51D 11    1.16D 10   -8.87D 09   -6.36D 10   -5.12D 08    0.0
 0.0         1.90D 12    1.28D 12   -1.93D 11    1.47D 11    7.70D 11    8.40D 09    0.0
 0.0         1.73D 10    8.62D 09   -8.15D 09    1.85D 10    1.85D 10    1.07D 10    0.0
 0.0         4.15D 11    2.06D 11   -2.51D 11    2.53D 11    4.00D 11    4.48D 10    0.0
 0.0         4.83D 11    2.39D 11   -2.03D 11    1.54D 11    4.07D 11    8.62D 09    0.0
 0.0         8.59D 09    4.28D 09    9.38D 09    9.13D 09    9.16D 09    1.87D 10    0.0
-3.00D 09   0.0          0.0          0.0          0.0          0.0          0.0         3.00D 09
```

Figure 6.4 CONFIGURATION I - Precalculated Matrices; BMIV, DA, and DV

CONFIGURATION AND MATRIX LAYER = 2

MATRICES ARE 7X7

--- SYSM ---

1.55D-04	0.0	0.0	0.0	0.0	0.0	7.77D-05
0.0	7.70D-05	1.09D-05	0.0	0.0	-6.42D-06	0.0
0.0	1.09D-05	1.97D-06	0.0	0.0	-1.48D-06	0.0
0.0	0.0	0.0	2.01D-04	-2.44D-05	1.44D-05	0.0
0.0	0.0	0.0	-2.44D-05	6.66D-06	-5.00D-06	0.0
0.0	-6.42D-06	-1.48D-06	1.44D-05	-5.00D-06	8.64D-06	0.0
7.77D-05	0.0	0.0	0.0	0.0	0.0	1.55D-04

--- DAMP ---

6.05D-01	0.0	0.0	0.0	0.0	0.0	-6.05D-01
0.0	1.32D 00	2.93D-01	5.54D-01	-1.69D-01	2.49D-01	0.0
0.0	2.93D-01	1.42D-01	1.00D-01	-3.70D-02	2.01D-02	0.0
0.0	5.54D-01	1.00D-01	1.51D 00	-3.36D-01	-5.39D-02	0.0
0.0	-1.69D-01	-3.70D-02	-3.36D-01	2.71D-01	-6.93D-02	0.0
0.0	2.49D-01	2.01D-02	-5.39D-02	-6.93D-02	4.69D-01	0.0
-6.05D-01	0.0	0.0	0.0	0.0	0.0	6.05D-01

--- STF ---

2.36D 05	0.0	0.0	0.0	0.0	0.0	-2.36D 05
0.0	2.29D 06	1.15D 06	0.0	0.0	1.15D 06	0.0
0.0	1.15D 06	7.63D 05	0.0	0.0	3.82D 05	0.0
0.0	0.0	0.0	1.39D 06	-5.09D 05	-5.09D 05	0.0
0.0	0.0	0.0	-5.09D 05	5.09D 05	2.54D 05	0.0
0.0	1.15D 06	3.82D 05	-5.09D 05	2.54D 05	1.27D 06	0.0
-2.36D 05	0.0	0.0	0.0	0.0	0.0	2.36D 05

Figure 6.5 CONFIGURATION II - Mass, Damping, and Stiffness

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CONFIGURATION AND MATRIX LAYER = 2

MATRICES ARE 7X1

COLUMN MATRICES FOR CALCULATION OF DELTA P

COLUMN MASS	COLUMN DAMPING	COLUMN STIFFNESS
0.0	0.0	0.0
0.0	-7.00D-02	0.0
0.0	-1.01D-02	0.0
-2.59D-05	9.12D-01	7.07D 05
0.0	-1.09D-01	0.0
0.0	5.66D-02	0.0
0.0	0.0	0.0

Figure 6.6 CONFIGURATION II - Precalculated Matrices; COLM, COLC, and COLK

CONFIGURATION AND MATRIX LAYER = 2

MATRICES ARE 7X7

- (BMIV) -

8.52D 03	0.0	0.0	0.0	0.0	0.0	-4.23D 03
0.0	4.99D 04	-2.66D 05	-4.36D 02	-1.11D 04	-1.31D 04	0.0
0.0	-2.66D 05	1.97D 06	7.04D 03	1.85D 05	2.17D 05	0.0
0.0	-4.36D 02	7.04D 03	9.03D 03	3.76D 04	7.23D 03	0.0
0.0	-1.11D 04	1.85D 05	3.76D 04	4.20D 05	1.93D 05	0.0
0.0	-1.31D 04	2.17D 05	7.23D 03	1.93D 05	2.29D 05	0.0
-4.23D 03	0.0	0.0	0.0	0.0	0.0	8.52D 03

- (DA) -

7.72D 03	0.0	0.0	0.0	0.0	0.0	-7.72D 03
0.0	-1.35D 04	-2.31D 04	4.78D 03	-5.86D 02	1.74D 03	0.0
0.0	2.53D 05	2.01D 05	-1.26D 04	4.71D 03	6.22D 04	0.0
0.0	1.91D 03	5.32D 02	1.10D 03	6.48D 03	3.28D 02	0.0
0.0	3.70D 04	1.51D 04	-8.22D 04	8.30D 04	6.01D 04	0.0
0.0	7.48D 04	2.53D 04	-5.16D 04	2.81D 04	9.49D 04	0.0
-7.72D 03	0.0	0.0	0.0	0.0	0.0	7.72D 03

- (DV) -

3.00D 09	0.0	0.0	0.0	0.0	0.0	-3.00D 09
0.0	-2.05D 11	-1.51D 11	1.17D 10	-8.77D 09	-6.35D 10	0.0
0.0	1.90D 12	1.28D 12	-1.95D 11	1.46D 11	7.68D 11	0.0
0.0	1.53D 10	7.64D 09	-1.03D 10	1.64D 10	1.64D 10	0.0
0.0	4.07D 11	2.02D 11	-2.60D 11	2.44D 11	3.91D 11	0.0
0.0	4.82D 11	2.39D 11	-2.05D 11	1.53D 11	4.05D 11	0.0
-3.00D 09	0.0	0.0	0.0	0.0	0.0	3.00D 09

Figure 6.7 CONFIGURATION II - Precalculated Matrices; BMIV, DA, and DV

CONFIGURATION AND MATRIX LAYER = 3

MATRICES ARE 7X7

--- SYSM ---

1.55D-04	7.77D-05	0.0	0.0	0.0	0.0	0.0
7.77D-05	2.32D-04	1.09D-05	0.0	0.0	-6.42D-06	0.0
0.0	1.09D-05	1.97D-06	0.0	0.0	-1.48D-06	0.0
0.0	0.0	0.0	2.01D-04	-2.44D-05	1.44D-05	-2.59D-05
0.0	0.0	0.0	-2.44D-05	6.66D-06	-5.00D-06	0.0
0.0	-6.42D-06	-1.48D-06	1.44D-05	-5.00D-06	8.64D-06	0.0
0.0	0.0	0.0	-2.59D-05	0.0	0.0	5.18D-05

--- DAMP ---

2.48D 00	1.05D 00	-7.37D-03	1.72D 00	-1.60D-01	9.80D-02	-6.62D-01
1.05D 00	3.49D 00	3.58D-01	2.09D 00	-3.08D-01	3.16D-01	-6.69D-01
-7.37D-03	3.58D-01	2.03D-01	1.02D-01	-3.48D-02	2.59D-03	-1.65D-02
1.72D 00	2.09D 00	1.02D-01	3.10D 00	-4.83D-01	3.25D-02	2.99D-01
-1.60D-01	-3.08D-01	-3.48D-02	-4.83D-01	2.86D-01	-8.02D-02	-5.40D-02
9.80D-02	3.16D-01	2.59D-03	3.25D-02	-8.02D-02	4.91D-01	2.90D-02
-6.62D-01	-6.69D-01	-1.65D-02	2.99D-01	-5.40D-02	2.90D-02	1.17D 00

--- STF ---

2.36D 05	-2.36D 05	0.0	0.0	0.0	0.0	0.0
-2.36D 05	2.53D 06	1.15D 06	0.0	0.0	1.15D 06	0.0
0.0	1.15D 06	7.63D 05	0.0	0.0	3.82D 05	0.0
0.0	0.0	0.0	1.39D 06	-5.09D 05	-5.09D 05	7.07D 05
0.0	0.0	0.0	-5.09D 05	5.09D 05	2.54D 05	0.0
0.0	1.15D 06	3.82D 05	-5.09D 05	2.54D 05	1.27D 06	0.0
0.0	0.0	0.0	7.07D 05	0.0	0.0	7.07D 05

Figure 6.8 CONFIGURATION III - Mass, Damping, and Stiffness

CONFIGURATION AND MATRIX LAYER = 3

MATRICES ARE 7X7

- (BMIV) -

8.18D 03	-3.62D 03	1.90D 04	1.34D 01	7.67D 02	9.06D 02	3.82D 01
-3.62D 03	7.24D 03	-3.81D 04	-7.89D 01	-1.58D 03	-1.82D 03	-2.14D 01
1.90D 04	-3.81D 04	7.50D 05	5.68D 03	1.35D 05	1.56D 05	2.79D 03
1.34D 01	-7.89D 01	5.68D 03	1.01D 04	4.23D 04	8.03D 03	4.97D 03
7.67D 02	-1.58D 03	1.35D 05	4.23D 04	4.38D 05	1.94D 05	2.08D 04
9.06D 02	-1.82D 03	1.56D 05	8.03D 03	1.94D 05	2.27D 05	3.98D 03
3.82D 01	-2.14D 01	2.79D 03	4.97D 03	2.08D 04	3.98D 03	2.15D 04

- (DA) -

1.63D 04	2.88D 03	2.48D 03	8.18D 03	-7.17D 02	9.49D 01	-3.28D 03
-1.09D 03	7.55D 03	-5.07D 03	5.46D 03	-5.96D 02	1.06D 03	-1.84D 03
3.14D 03	1.73D 05	1.35D 05	-1.18D 04	5.78D 03	5.79D 04	2.73D 03
8.08D 03	9.12D 03	6.32D 02	1.32D 04	6.10D 03	1.01D 03	6.76D 03
7.20D 03	4.42D 04	1.61D 04	-5.59D 04	8.36D 04	6.17D 04	1.74D 04
1.65D 03	7.66D 04	2.57D 04	-4.63D 04	2.80D 04	9.60D 04	1.22D 03
-8.56D 03	-8.19D 03	-4.62D-01	1.22D 04	1.98D 03	1.07D 03	2.56D 04

- (DV) -

2.78D 09	1.18D 10	1.07D 10	-8.06D 08	6.14D 08	4.46D 09	3.65D 07
-2.56D 09	-2.66D 10	-2.15D 10	1.61D 09	-1.23D 09	-8.93D 09	-7.09D 07
1.35D 10	9.37D 11	5.88D 11	-1.38D 11	1.06D 11	4.73D 11	5.99D 09
2.17D 07	1.55D 10	7.31D 09	-8.05D 09	1.84D 10	1.79D 10	1.07D 10
5.54D 08	3.72D 11	1.75D 11	-2.48D 11	2.51D 11	3.86D 11	4.46D 10
6.43D 08	4.34D 11	2.04D 11	-2.00D 11	1.52D 11	3.91D 11	8.49D 09
1.41D 07	7.69D 09	3.63D 09	9.44D 09	9.09D 09	8.87D 09	1.87D 10

Figure 6.9 CONFIGURATION III - Precalculated Matrices; BMIV, DA, and DV

CONFIGURATION AND MATRIX LAYER = 4

MATRICES ARE 6X6

--- SYSM ---

1.55D-04	7.77D-05	0.0	0.0	0.0	0.0
7.77D-05	2.32D-04	1.09D-05	0.0	0.0	-6.42D-06
0.0	1.09D-05	1.97D-06	0.0	0.0	-1.48D-06
0.0	0.0	0.0	2.01D-04	-2.44D-05	1.44D-05
0.0	0.0	0.0	-2.44D-05	6.66D-06	-5.00D-06
0.0	-6.42D-06	-1.48D-06	1.44D-05	-5.00D-06	8.64D-06

--- DAMP ---

2.48D 00	1.05D 00	-7.37D-03	1.72D 00	-1.60D-01	9.80D-02
1.05D 00	3.49D 00	3.58D-01	2.09D 00	-3.08D-01	3.16D-01
-7.37D-03	3.58D-01	2.03D-01	1.02D-01	-3.48D-02	2.59D-03
1.72D 00	2.09D 00	1.02D-01	3.10D 00	-4.83D-01	3.25D-02
-1.60D-01	-3.08D-01	-3.48D-02	-4.83D-01	2.86D-01	-8.02D-02
9.80D-02	3.16D-01	2.59D-03	3.25D-02	-8.02D-02	4.91D-01

--- STF ---

2.36D 05	-2.36D 05	0.0	0.0	0.0	0.0
-2.36D 05	2.53D 06	1.15D 06	0.0	0.0	1.15D 06
0.0	1.15D 06	7.63D 05	0.0	0.0	3.82D 05
0.0	0.0	0.0	1.39D 06	-5.09D 05	-5.09D 05
0.0	0.0	0.0	-5.09D 05	5.09D 05	2.54D 05
0.0	1.15D 06	3.82D 05	-5.09D 05	2.54D 05	1.27D 06

Figure 6.10 CONFIGURATION IV - Mass, Damping, and Stiffness

CONFIGURATION AND MATRIX LAYER = 4

MATRICES ARE 6X1

COLUMN MATRICES FOR CALCULATION OF DELTA P

COLUMN MASS	COLUMN DAMPING	COLUMN STIFFNESS
0.0	-6.62D-01	0.0
0.0	-6.69D-01	0.0
0.0	-1.65D-02	0.0
-2.59D-05	2.99D-01	7.07D 05
0.0	-5.40D-02	0.0
0.0	2.90D-02	0.0

Figure 6.11 CONFIGURATION IV - Precalculated Matrices; COLM, COLC, and COLK

CONFIGURATION AND MATRIX LAYER = 4

MATRICES ARE 6X6

- (BMIV) -

8.18D 03	-3.62D 03	1.90D 04	4.55D 00	7.30D 02	8.99D 02
-3.62D 03	7.24D 03	-3.81D 04	-7.39D 01	-1.56D 03	-1.82D 03
1.90D 04	-3.81D 04	7.49D 05	5.03D 03	1.32D 05	1.56D 05
4.55D 00	-7.39D 01	5.03D 03	9.00D 03	3.75D 04	7.11D 03
7.30D 02	-1.56D 03	1.32D 05	3.75D 04	4.18D 05	1.90D 05
8.99D 02	-1.82D 03	1.56D 05	7.11D 03	1.90D 05	2.26D 05

- (DA) -

1.63D 04	2.90D 03	2.48D 03	8.16D 03	-7.20D 02	9.30D 01
-1.10D 03	7.55D 03	-5.07D 03	5.47D 03	-5.94D 02	1.06D 03
4.26D 03	1.74D 05	1.35D 05	-1.33D 04	5.52D 03	5.78D 04
1.01D 04	1.10D 04	6.32D 02	1.04D 04	5.64D 03	7.64D 02
1.55D 04	5.21D 04	1.61D 04	-6.78D 04	8.17D 04	6.07D 04
3.24D 03	7.81D 04	2.57D 04	-4.86D 04	2.76D 04	9.58D 04

- (DV) -

2.78D 09	1.18D 10	1.07D 10	-8.23D 08	5.98D 08	4.45D 09
-2.56D 09	-2.66D 10	-2.15D 10	1.62D 09	-1.22D 09	-8.93D 09
1.35D 10	9.36D 11	5.88D 11	-1.40D 11	1.04D 11	4.72D 11
1.85D 07	1.37D 10	6.47D 09	-1.02D 10	1.63D 10	1.58D 10
5.40D 08	3.65D 11	1.72D 11	-2.57D 11	2.42D 11	3.77D 11
6.41D 08	4.32D 11	2.03D 11	-2.02D 11	1.50D 11	3.90D 11

Figure 6.12 CONFIGURATION IV - Precalculated Matrices; BMIV, DA, and DV

CONFIGURATION AND MATRIX LAYER = 5

MATRICES ARE 7X7

--- SYSM ---

7.70D-05	1.09D-05	0.0	0.0	-6.42D-06	0.0	0.0
1.09D-05	1.97D-06	0.0	0.0	-1.48D-06	0.0	0.0
0.0	0.0	2.01D-04	-2.44D-05	1.44D-05	-2.59D-05	0.0
0.0	0.0	-2.44D-05	6.66D-06	-5.00D-06	0.0	0.0
-6.42D-06	-1.48D-06	1.44D-05	-5.00D-06	8.64D-06	0.0	0.0
0.0	0.0	-2.59D-05	0.0	0.0	5.18D-05	0.0
0.0	0.0	0.0	0.0	0.0	0.0	1.55D-04

--- DAMP ---

1.32D 00	2.93D-01	5.54D-01	-1.69D-01	2.49D-01	-7.00D-02	0.0
2.93D-01	1.42D-01	1.00D-01	-3.70D-02	2.01D-02	-1.01D-02	0.0
5.54D-01	1.00D-01	1.51D 00	-3.36D-01	-5.39D-02	9.12D-01	0.0
-1.69D-01	-3.70D-02	-3.36D-01	2.71D-01	-6.93D-02	-1.09D-01	0.0
2.49D-01	2.01D-02	-5.39D-02	-6.93D-02	4.69D-01	5.66D-02	0.0
-7.00D-02	-1.01D-02	9.12D-01	-1.09D-01	5.66D-02	9.31D-01	0.0
0.0	0.0	0.0	0.0	0.0	0.0	6.05D-01

--- STF ---

2.29D 06	1.15D 06	0.0	0.0	1.15D 06	0.0	0.0
1.15D 06	7.63D 05	0.0	0.0	3.82D 05	0.0	0.0
0.0	0.0	1.39D 06	-5.09D 05	-5.09D 05	7.07D 05	0.0
0.0	0.0	-5.09D 05	5.09D 05	2.54D 05	0.0	0.0
1.15D 06	3.82D 05	-5.09D 05	2.54D 05	1.27D 06	0.0	0.0
0.0	0.0	7.07D 05	0.0	0.0	7.07D 05	0.0
0.0	0.0	0.0	0.0	0.0	0.0	2.36D 05

Figure 6.13 CONFIGURATION V - Mass, Damping, and Stiffness

CONFIGURATION AND MATRIX LAYER = 5

MATRICES ARE 7X1

COLUMN MATRICES FOR CALCULATION OF DELTA P

COLUMN MASS	COLUMN DAMPING	COLUMN STIFFNESS
0.0	0.0	0.0
0.0	0.0	0.0
0.0	0.0	0.0
0.0	0.0	0.0
0.0	0.0	0.0
0.0	0.0	0.0
7.77D-05	-6.05D-01	-2.36D 05

Figure 6.14 CONFIGURATION V - Precalculated Matrices; COLM, COLC, and COLK

CONFIGURATION AND MATRIX LAYER = 5

MATRICES ARE 7X7

- (BMIV) -

4.99D 04	-2.66D 05	-4.90D 02	-1.14D 04	-1.31D 04	-2.34D 02	0.0
-2.66D 05	1.97D 06	7.95D 03	1.89D 05	2.18D 05	3.94D 03	0.0
-4.90D 02	7.95D 03	1.02D 04	4.24D 04	8.16D 03	4.96D 03	0.0
-1.14D 04	1.89D 05	4.24D 04	4.40D 05	1.97D 05	2.09D 04	0.0
-1.31D 04	2.18D 05	8.16D 03	1.97D 05	2.30D 05	4.04D 03	0.0
-2.34D 02	3.94D 03	4.96D 03	2.09D 04	4.04D 03	2.15D 04	0.0
0.0	0.0	0.0	0.0	0.0	0.0	6.42D 03

- (DA) -

-1.35D 04	-2.31D 04	4.56D 03	-6.00D 02	1.73D 03	-9.68D 02	0.0
2.53D 05	2.01D 05	-8.87D 03	4.95D 03	6.25D 04	1.29D 03	0.0
1.81D 03	5.51D 02	5.75D 03	6.77D 03	6.55D 02	9.68D 03	0.0
3.66D 04	1.52D 04	-6.27D 04	8.42D 04	6.15D 04	2.01D 04	0.0
7.47D 04	2.53D 04	-4.78D 04	2.83D 04	9.52D 04	1.49D 03	0.0
-4.46D 02	7.92D 01	2.01D 04	1.26D 03	1.42D 03	2.25D 04	0.0
0.0	0.0	0.0	0.0	0.0	0.0	3.88D 03

- (DV) -

-2.05D 11	-1.51D 11	1.16D 10	-8.87D 09	-6.36D 10	-5.12D 08	0.0
1.90D 12	1.28D 12	-1.93D 11	1.47D 11	7.70D 11	8.40D 09	0.0
1.73D 10	8.62D 09	-8.15D 09	1.85D 10	1.85D 10	1.07D 10	0.0
4.15D 11	2.06D 11	-2.51D 11	2.53D 11	4.00D 11	4.48D 10	0.0
4.83D 11	2.39D 11	-2.03D 11	1.54D 11	4.07D 11	8.62D 09	0.0
8.59D 09	4.28D 09	9.38D 09	9.13D 09	9.16D 09	1.87D 10	0.0
0.0	0.0	0.0	0.0	0.0	0.0	1.51D 09

Figure 6.15 CONFIGURATION V - Precalculated Matrics; BMIV, DA, and DV

CONFIGURATION AND MATRIX LAYER = 6

MATRICES ARE 6X6

--- SYSM ---

7.70D-05	1.09D-05	0.0	0.0	-6.42D-06	0.0
1.09D-05	1.97D-06	0.0	0.0	-1.48D-06	0.0
0.0	0.0	2.01D-04	-2.44D-05	1.44D-05	0.0
0.0	0.0	-2.44D-05	6.66D-06	-5.00D-06	0.0
-6.42D-06	-1.48D-06	1.44D-05	-5.00D-06	8.64D-06	0.0
0.0	0.0	0.0	0.0	0.0	1.55D-04

--- DAMP ---

1.32D 00	2.93D-01	5.54D-01	-1.69D-01	2.49D-01	0.0
2.93D-01	1.42D-01	1.00D-01	-3.70D-02	2.01D-02	0.0
5.54D-01	1.00D-01	1.51D 00	-3.36D-01	-5.39D-02	0.0
-1.69D-01	-3.70D-02	-3.36D-01	2.71D-01	-6.93D-02	0.0
2.49D-01	2.01D-02	-5.39D-02	-6.93D-02	4.69D-01	0.0
0.0	0.0	0.0	0.0	0.0	6.05D-01

--- STF ---

2.29D 06	1.15D 06	0.0	0.0	1.15D 06	0.0
1.15D 06	7.63D 05	0.0	0.0	3.82D 05	0.0
0.0	0.0	1.39D 06	-5.09D 05	-5.09D 05	0.0
0.0	0.0	-5.09D 05	5.09D 05	2.54D 05	0.0
1.15D 06	3.82D 05	-5.09D 05	2.54D 05	1.27D 06	0.0
0.0	0.0	0.0	0.0	0.0	2.36D 05

Figure 6.16 CONFIGURATION VI - Mass, Damping, and Stiffness

CONFIGURATION AND MATRIX LAYER = 6

MATRICES ARE 6X1

COLUMN MATRICES FOR CALCULATION OF DELTA P

COLUMN MASS	COLUMN DAMPING	COLUMN STIFFNESS
0.0	0.0	0.0
0.0	0.0	0.0
0.0	0.0	0.0
0.0	0.0	0.0
0.0	0.0	0.0
7.77D-05	-6.05D-01	-2.36D 05

Figure 6.17 CONFIGURATION VI - Precalculated Matrices; COLM, COLC, and COLK

CONFIGURATION = 6 MATRIX LAYER = 1

MATRICES ARE 6X1

COLUMN MATRICES FOR CALCULATION OF DELTA P

COLUMN MASS	COLUMN DAMPING	COLUMN STIFFNESS
0.0	-7.00D-02	0.0
0.0	-1.01D-02	0.0
-2.59D-05	9.12D-01	7.07D 05
0.0	-1.09D-01	0.0
0.0	5.66D-02	0.0
0.0	0.0	0.0

Figure 6.13 CONFIGURATION VI - Precalculated Matrices; COLM, COLC, and COLK

CONFIGURATION AND MATRIX LAYER = 6

MATRICES ARE 6X6

- (BMIV) -

4.99D 04	-2.66D 05	-4.36D 02	-1.11D 04	-1.31D 04	0.0
-2.66D 05	1.97D 06	7.04D 03	1.85D 05	2.17D 05	0.0
-4.36D 02	7.04D 03	9.03D 03	3.76D 04	7.23D 03	0.0
-1.11D 04	1.85D 05	3.76D 04	4.20D 05	1.93D 05	0.0
-1.31D 04	2.17D 05	7.23D 03	1.93D 05	2.29D 05	0.0
0.0	0.0	0.0	0.0	0.0	6.42D 03

- (DA) -

-1.35D 04	-2.31D 04	4.78D 03	-5.86D 02	1.74D 03	0.0
2.53D 05	2.01D 05	-1.26D 04	4.71D 03	6.22D 04	0.0
1.91D 03	5.32D 02	1.10D 03	6.48D 03	3.28D 02	0.0
3.70D 04	1.51D 04	-8.22D 04	8.30D 04	6.01D 04	0.0
7.48D 04	2.53D 04	-5.16D 04	2.81D 04	9.49D 04	0.0
0.0	0.0	0.0	0.0	0.0	3.88D 03

- (DV) -

-2.05D 11	-1.51D 11	1.17D 10	-8.77D 09	-6.35D 10	0.0
1.90D 12	1.28D 12	-1.95D 11	1.46D 11	7.68D 11	0.0
1.53D 10	7.64D 09	-1.03D 10	1.64D 10	1.64D 10	0.0
4.07D 11	2.02D 11	-2.60D 11	2.44D 11	3.91D 11	0.0
4.82D 11	2.39D 11	-2.05D 11	1.53D 11	4.05D 11	0.0
0.0	0.0	0.0	0.0	0.0	1.51D 09

Figure 6.19 CONFIGURATION VI - Precalculated Matrices; BMIV, DA, and DV

CONFIGURATION AND MATRIX LAYER = 7

MATRICES ARE 6X6

--- SYSM ---

2.32D-04	1.09D-05	0.0	0.0	-6.42D-06	0.0
1.09D-05	1.97D-06	0.0	0.0	-1.48D-06	0.0
0.0	0.0	2.01D-04	-2.44D-05	1.44D-05	-2.59D-05
0.0	0.0	-2.44D-05	6.66D-06	-5.00D-06	0.0
-6.42D-06	-1.48D-06	1.44D-05	-5.00D-06	8.64D-06	0.0
0.0	0.0	-2.59D-05	0.0	0.0	5.18D-05

--- DAMP ---

3.49D 00	3.58D-01	2.09D 00	-3.08D-01	3.16D-01	-6.69D-01
3.58D-01	2.03D-01	1.02D-01	-3.48D-02	2.59D-03	-1.65D-02
2.09D 00	1.02D-01	3.10D 00	-4.83D-01	3.25D-02	2.99D-01
-3.08D-01	-3.48D-02	-4.83D-01	2.86D-01	-8.02D-02	-5.40D-02
3.16D-01	2.59D-03	3.25D-02	-8.02D-02	4.91D-01	2.90D-02
-6.69D-01	-1.65D-02	2.99D-01	-5.40D-02	2.90D-02	1.17D 00

--- STF ---

2.53D 06	1.15D 06	0.0	0.0	1.15D 06	0.0
1.15D 06	7.63D 05	0.0	0.0	3.82D 05	0.0
0.0	0.0	1.39D 06	-5.09D 05	-5.09D 05	7.07D 05
0.0	0.0	-5.09D 05	5.09D 05	2.54D 05	0.0
1.15D 06	3.82D 05	-5.09D 05	2.54D 05	1.27D 06	0.0
0.0	0.0	7.07D 05	0.0	0.0	7.07D 05

Figure 6.20 CONFIGURATION VII - Mass, Damping, and Stiffness

CONFIGURATION AND MATRIX LAYER = 7

MATRICES ARE 6X1

COLUMN MATRICES FOR CALCULATION OF DELTA P

COLUMN MASS	COLUMN DAMPING	COLUMN STIFFNESS
7.77D-05	1.05D 00	-2.36D 05
0.0	-7.37D-03	0.0
0.0	1.72D 00	0.0
0.0	-1.60D-01	0.0
0.0	9.80D-02	0.0
0.0	-6.62D-01	0.0

Figure 6.21 CONFIGURATION VII - Precalculated Matrices; COLM, COLC, and COLK

CONFIGURATION AND MATRIX LAYER = 7

MATRICES ARE 6X6

- (BMIV) -

5.65D 03	-2.97D 04	-7.29D 01	-1.24D 03	-1.42D 03	-4.55D 00
-2.97D 04	7.05D 05	5.65D 03	1.33D 05	1.54D 05	2.71D 03
-7.29D 01	5.65D 03	1.01D 04	4.23D 04	8.03D 03	4.97D 03
-1.24D 03	1.33D 05	4.23D 04	4.38D 05	1.93D 05	2.08D 04
-1.42D 03	1.54D 05	8.03D 03	1.93D 05	2.27D 05	3.97D 03
-4.55D 00	2.71D 03	4.97D 03	2.08D 04	3.97D 03	2.15D 04

- (DA) -

8.83D 03	-3.98D 03	9.07D 03	-9.13D 02	1.10D 03	-3.29D 03
1.67D 05	1.29D 05	-3.08D 04	7.44D 03	5.77D 04	1.04D 04
9.12D 03	6.28D 02	1.32D 04	6.10D 03	1.01D 03	6.76D 03
4.39D 04	1.59D 04	-5.67D 04	8.37D 04	6.17D 04	1.77D 04
7.63D 04	2.54D 04	-4.72D 04	2.81D 04	9.60D 04	1.59D 03
-8.21D 03	-1.21D 01	1.22D 04	1.98D 03	1.07D 03	2.56D 04

- (DV) -

-2.14D 10	-1.68D 10	1.25D 09	-9.58D 08	-6.96D 09	-5.48D 07
9.09D 11	5.63D 11	-1.37D 11	1.04D 11	4.62D 11	5.91D 09
1.55D 10	7.29D 09	-8.04D 09	1.84D 10	1.79D 10	1.07D 10
3.71D 11	1.74D 11	-2.48D 11	2.50D 11	3.85D 11	4.46D 10
4.32D 11	2.03D 11	-2.00D 11	1.52D 11	3.91D 11	8.48D 09
7.64D 09	3.58D 09	9.44D 09	9.09D 09	8.85D 09	1.87D 10

Figure 6.22 CONFIGURATION VII - Precalculated Matrices; BMIV, DA, and DV

CONFIGURATION AND MATRIX LAYER = 8

MATRICES ARE 5X5

--- SYSM ---

2.32D-04	1.09D-05	0.0	0.0	-6.42D-06
1.09D-05	1.97D-06	0.0	0.0	-1.48D-06
0.0	0.0	2.01D-04	-2.44D-05	1.44D-05
0.0	0.0	-2.44D-05	6.66D-06	-5.00D-06
-6.42D-06	-1.48D-06	1.44D-05	-5.00D-06	8.64D-06

--- DAMP ---

3.49D 00	3.58D-01	2.09D 00	-3.08D-01	3.16D-01
3.58D-01	2.03D-01	1.02D-01	-3.48D-02	2.59D-03
2.09D 00	1.02D-01	3.10D 00	-4.83D-01	3.25D-02
-3.08D-01	-3.48D-02	-4.83D-01	2.86D-01	-8.02D-02
3.16D-01	2.59D-03	3.25D-02	-8.02D-02	4.91D-01

--- STF ---

2.53D 06	1.15D 06	0.0	0.0	1.15D 06
1.15D 06	7.63D 05	0.0	0.0	3.82D 05
0.0	0.0	1.39D 06	-5.09D 05	-5.09D 05
0.0	0.0	-5.09D 05	5.09D 05	2.54D 05
1.15D 06	3.82D 05	-5.09D 05	2.54D 05	1.27D 06

Figure 6.23 CONFIGURATION VIII - Mass, Damping, and Stiffness

CONFIGURATION AND MATRIX LAYER = 8

MATRICES ARE 5X1

COLUMN MATRICES FOR CALCULATION OF DELTA P

COLUMN MASS	COLUMN DAMPING	COLUMN STIFFNESS
7.77D-05	1.05D 00	-2.36D 05
0.0	-7.37D-03	0.0
0.0	1.72D 00	0.0
0.0	-1.60D-01	0.0
0.0	9.80D-02	0.0

CONFIGURATION = 8, MATRIX LAYER = 3

MATRICES ARE 5X1

COLUMN MATRICES FOR CALCULATION OF DELTA P

COLUMN MASS	COLUMN DAMPING	COLUMN STIFFNESS
0.0	-6.69D-01	0.0
0.0	-1.65D-02	0.0
-2.59D-05	2.99D-01	7.07D 05
0.0	-5.40D-02	0.0
0.0	2.90D-02	0.0

Figure 6.24 CONFIGURATION VIII - Precalculated Matrices; COLM, COLC, and COLK

CONFIGURATION AND MATRIX LAYER = 8

MATRICES ARE 5X5

- (BMIV) -

5.65D 03	-2.97D 04	-7.19D 01	-1.24D 03	-1.42D 03
-2.97D 04	7.05D 05	5.02D 03	1.31D 05	1.54D 05
-7.19D 01	5.02D 03	9.00D 03	3.75D 04	7.11D 03
-1.24D 03	1.31D 05	3.75D 04	4.18D 05	1.90D 05
-1.42D 03	1.54D 05	7.11D 03	1.90D 05	2.26D 05

- (DA) -

8.83D 03	-3.98D 03	9.07D 03	-9.12D 02	1.10D 03
1.68D 05	1.29D 05	-3.23D 04	7.19D 03	5.75D 04
1.10D 04	6.31D 02	1.04D 04	5.64D 03	7.64D 02
5.19D 04	1.59D 04	-6.85D 04	8.18D 04	6.07D 04
7.78D 04	2.54D 04	-4.95D 04	2.77D 04	9.58D 04

- (DV) -

-2.14D 10	-1.68D 10	1.26D 09	-9.56D 08	-6.96D 09
9.08D 11	5.63D 11	-1.38D 11	1.03D 11	4.61D 11
1.37D 10	6.47D 09	-1.02D 10	1.63D 10	1.58D 10
3.64D 11	1.71D 11	-2.57D 11	2.42D 11	3.77D 11
4.31D 11	2.02D 11	-2.02D 11	1.50D 11	3.89D 11

Figure 6.25 CONFIGURATION VIII - Precalculated Matrices; BMIV, DA, and DV

C. SAMPLE PROBLEMS

One set of results for 11,000 RPM was obtained in CALCOMP graph form and as AGT graphic display photographs. At this high speed of cam rotation, the pushrod is frequently thrown off the cam. The results are completely analyzed with numerious reference points plotted on the graphs.

The second example problem was chosen at a slower speed, 9,000 RPM. At this speed the pushrod remains in contact with the cam. A third intermediate example, 10,000 RPM was chosen for a comparison between the two above examples. Figure 6.26 shows the relationship between the sample problems.

Photographs from the AGT display are presented after the CALCOMP graphs for each case of example one. It is noted that large scale factors are introduced for both bending and axial deformation as an aid to the user.

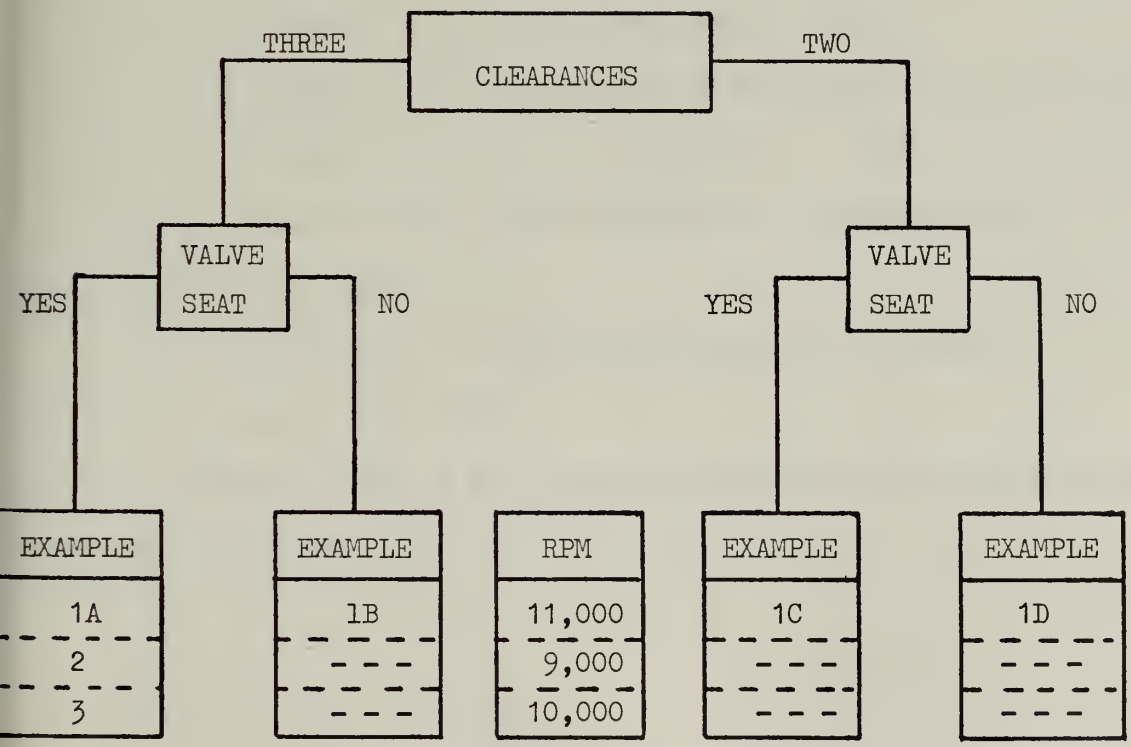


Figure 6.26 SAMPLE NUMERICAL RESULTS

1. Example 1A, Three Clearance, 11,000 RPM, Valve Seat

This analysis will commence at 270 degrees of cam rotation. One cycle will be discussed, from point (A) to point (AA). The following figures are utilized for the analysis:

a. Figure 6.27

(1) Displacement difference between cam and pushrod $(q_1 - q_9) \times 10^{-2}$

(2) Displacement of lower end of pushrod i.e. follower, $q_1 \times 10^{-1}$

(3) Cam Profile $q_9 \times 10^{-1}$

b. Figure 6.28

(1) Displacement difference between pushrod and rocker $(q_2 - q_8) \times 10^{-2}$

(2) Displacement difference between cam and pushrod $(q_1 - q_9) \times 10^{-2}$

c. Figure 6.29 Force on the Pushrod $F_1 \times 10^3$

d. Figure 6.30 Force on the Rocker $F_2 \times 10^2$

e. Figure 6.31 Displacement of the Valve $q_7 \times 10^{-1}$

f. Figure 6.32 Force on the Valve $F_7 \times 10^3$

g. Figure 6.33 Axial Oscillation of the Valve Stem $(q_7 - q_6) \times 10^{-3}$

h. Figure 6.34 Axial Oscillations of the Pushrod $(q_8 - q_1) \times 10^{-3}$

Figures 6.33 and 6.34 have been included for completeness and are not annotated.

The following reference points approximately correspond to the indicated degrees of cam rotation, Table 6.1

Reference Point	Degrees of Cam Rotation	Reference Point	Degrees of Cam Rotation
A	270	I	380
B	288	J	418
C	294	K	430
D	300	L	448
E	336	M	459
F	346	N	579
G	357	P	583
H	363	AA	630

Table 6.1 Graph Reference Points and Degrees of Cam Rotation for Figures 6.27 - 6.32

At point (A), the cam is at its lowest extreme and is starting to rise. The pushrod is floating between the cam and rocker, with downward motion. The valve has just undergone a severe oscillation and has resumed its upward motion.

At point (B), the cam and pushrod impact and remain in contact for a short period, (B-C). The rising cam and force of impact create severe oscillation of the pushrod and a bounce occurs. The pushrod is again thrown clear of the cam and floats (C-E).

At point (D), the valve has bounced against the valve seat, creating severe oscillation and more bouncing of the valve (D-E). The pushrod is floating thus is not affected by this impact.

At point (E), the rising pushrod now impacts against the rocker, and valve against the valve seat. At point (E), the valve has again reseated and the rocker has become almost stationary. This allows the rising pushrod to impact against the rocker.

The pushrod bounces off the rocker (F-H) and again floats (F-H), now having downward motion and also creating downward motion of the valve.

The rising cam almost immediately contacts the pushrod (G). The resulting motion creates positive contact between cam, pushrod, and rocker (H-I), and the valve bounces cease and it resumes its downward harmonic motion. At point (I), the speed of the cam throws the pushrod clear. Immediately separation occurs at the rocker- pushrod due to inertial effects. Several bounces at this clearance are observed (J-K-L-M), until the system reaches its extreme, point (M), i.e. the cam now with downward motion begins falling away from the pushrod. The valve spring, having reached the maximum extension, reverses the motion of the valve upward. The rocker and pushrod are now in contact (M) and both have downward motion.

At point (N), the valve impacts against the seat which results in severe oscillations and valve bounce (P-AA). With the gross motion of the rocker halted, the pushrod floats clear (P-AA). The cycle then repeats.

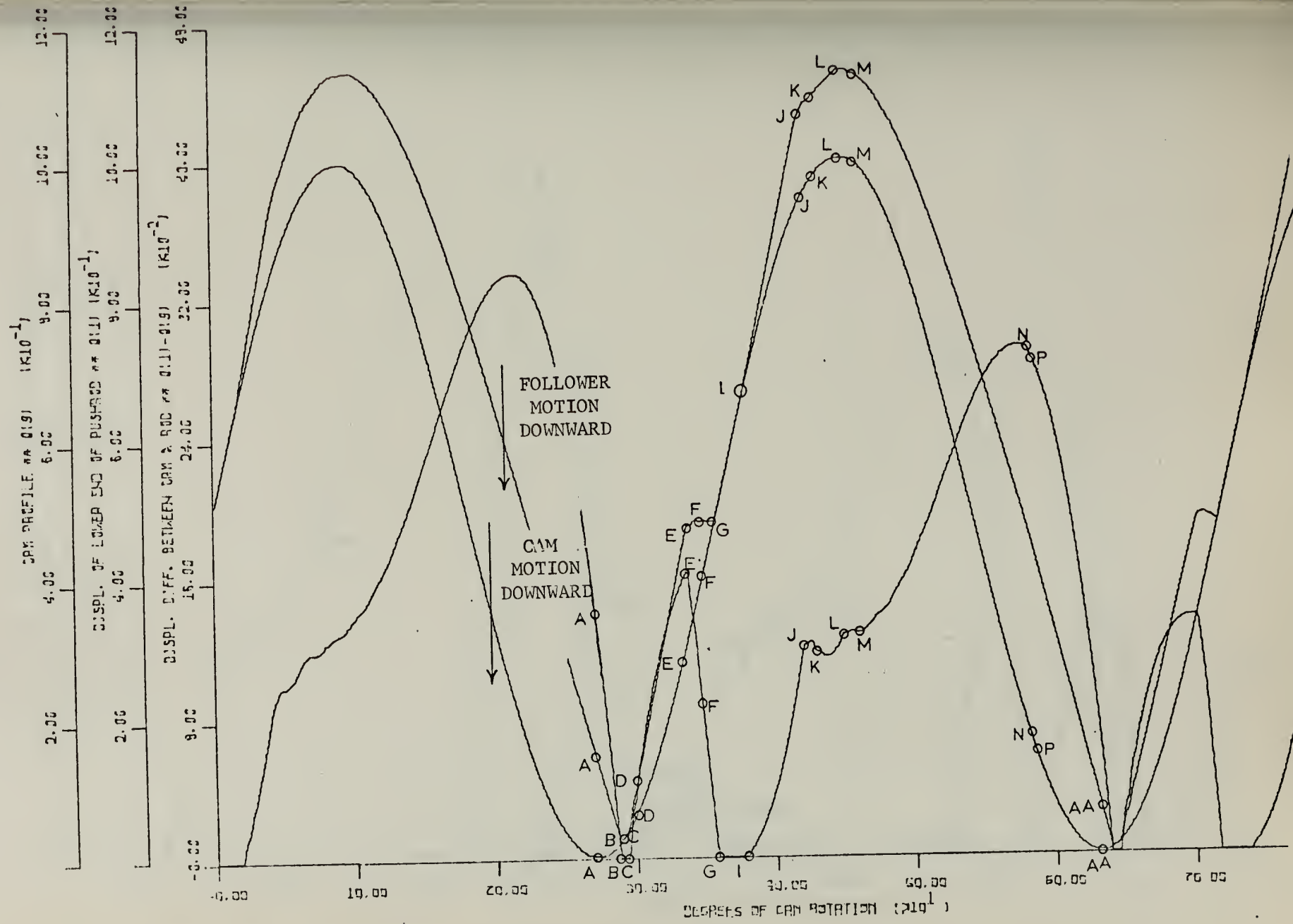


Figure 6.27 THREE CLEARANCES 11,000 RPM VALVE SEAT

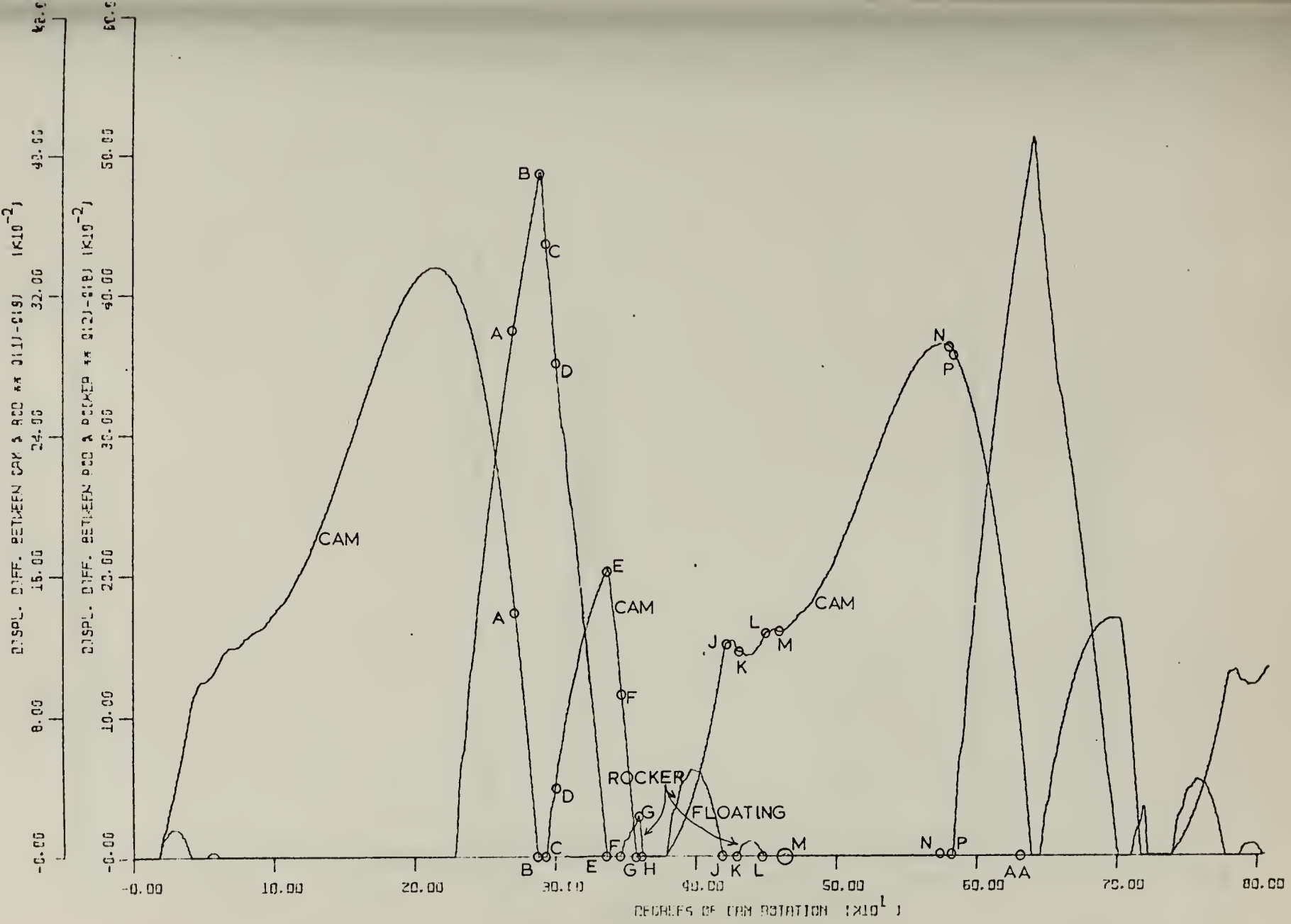


Figure 6.28 THREE CLEARANCES 11,000 RPM VALVE SEAT

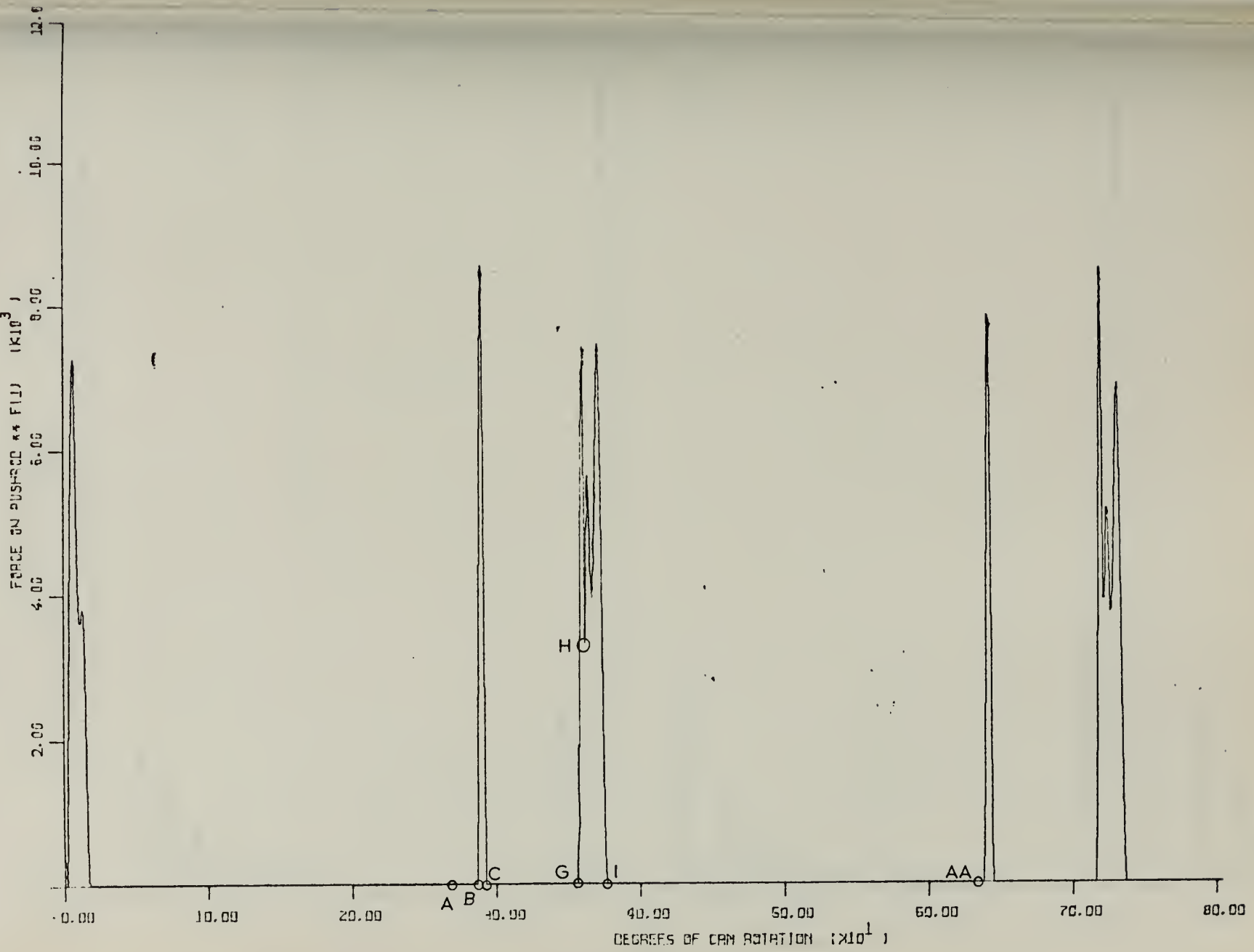


Figure 6.29 THREE CLEARANCES 11,000 RPM VALVE SEAT

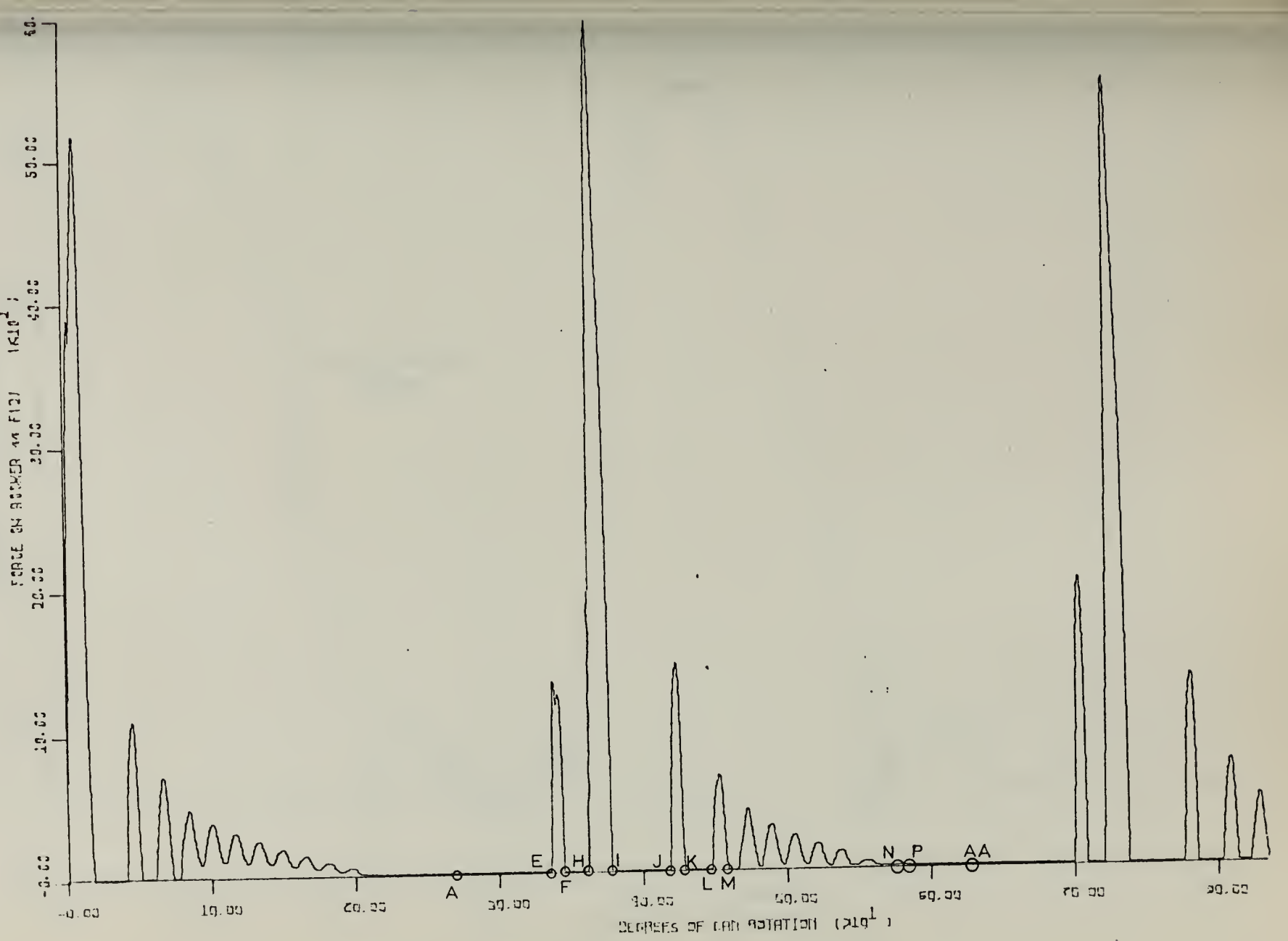


Figure 6.30 THREE CLEARANCES 11,000 RPM VALVE SEAT

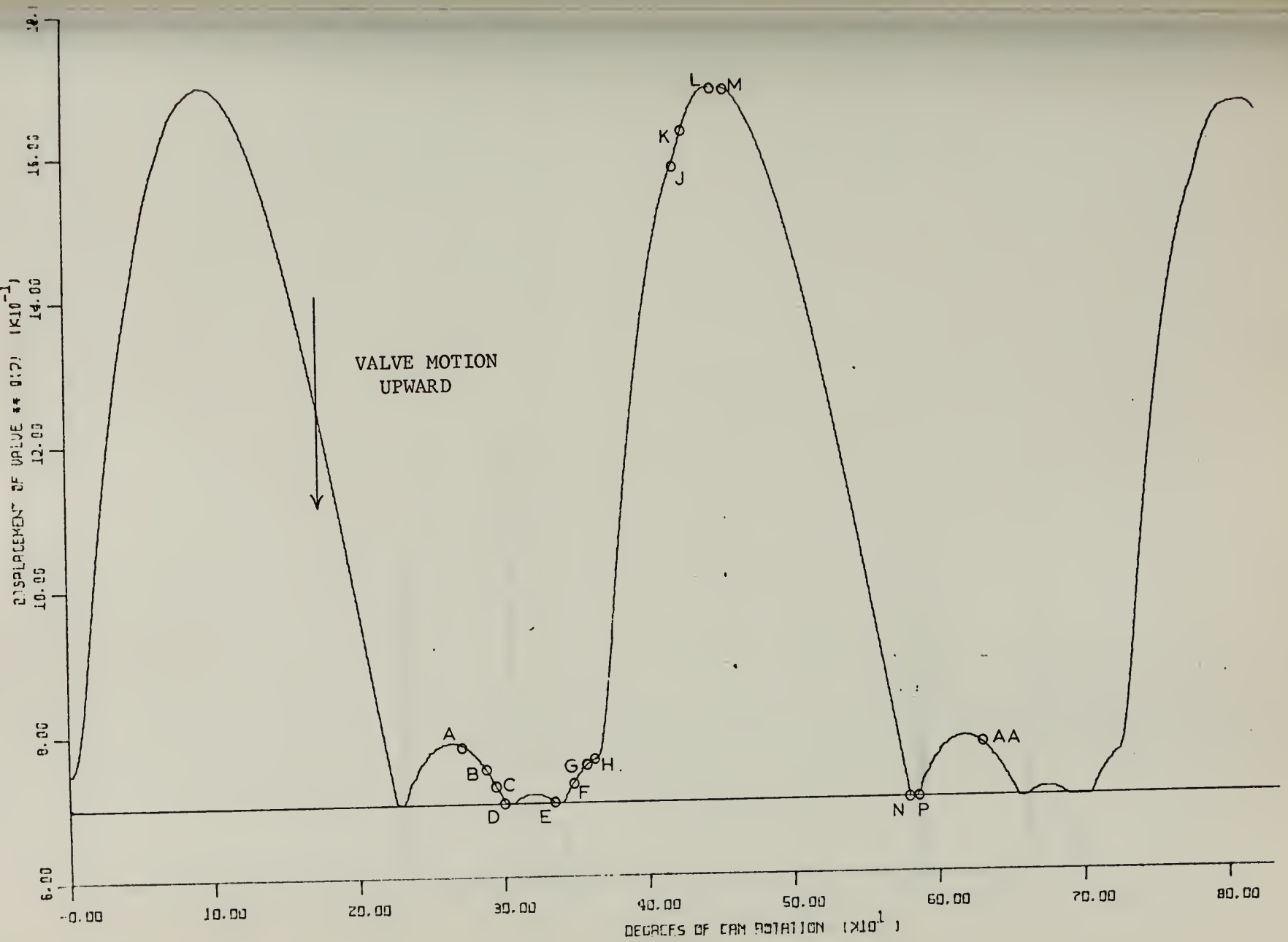


Figure 6.31 THREE CLEARANCES 11,000 RPM VALVE SEAT

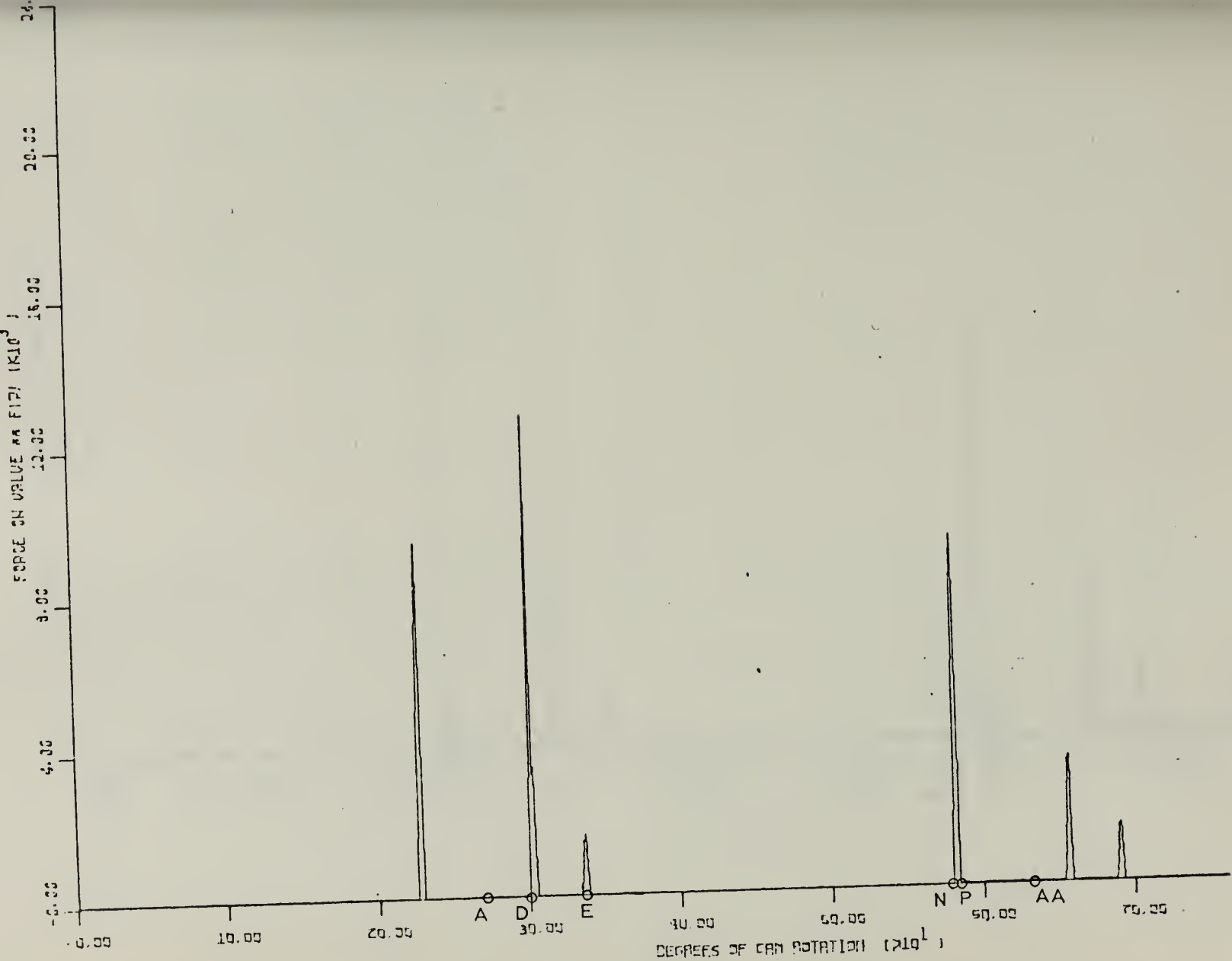


Figure 6.32 THREE CLEARANCES 11,000 RPM VALVE SEAT

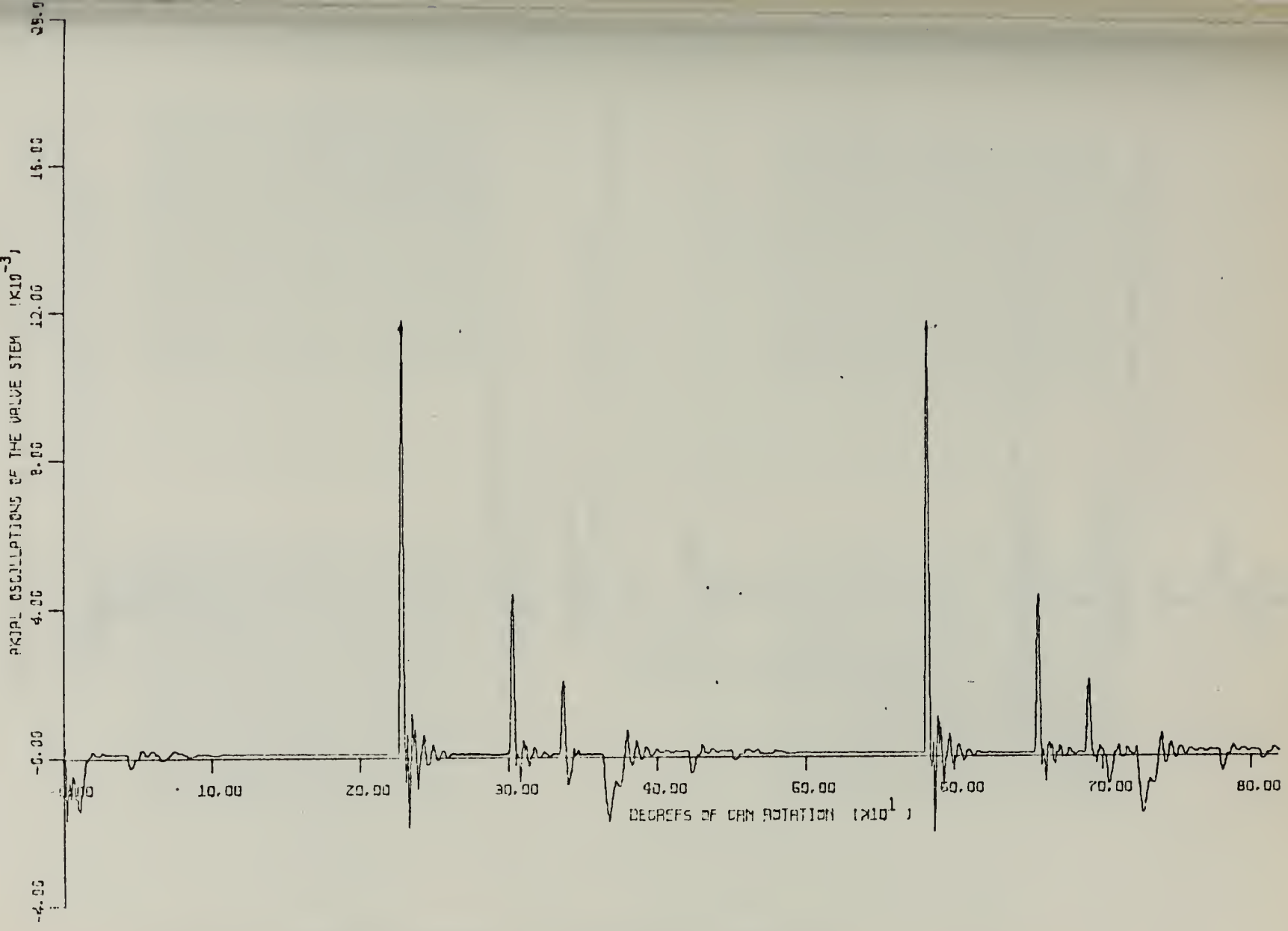


Figure 6.33 THREE CLEARANCES 11,000 RPM VALVE SEAT

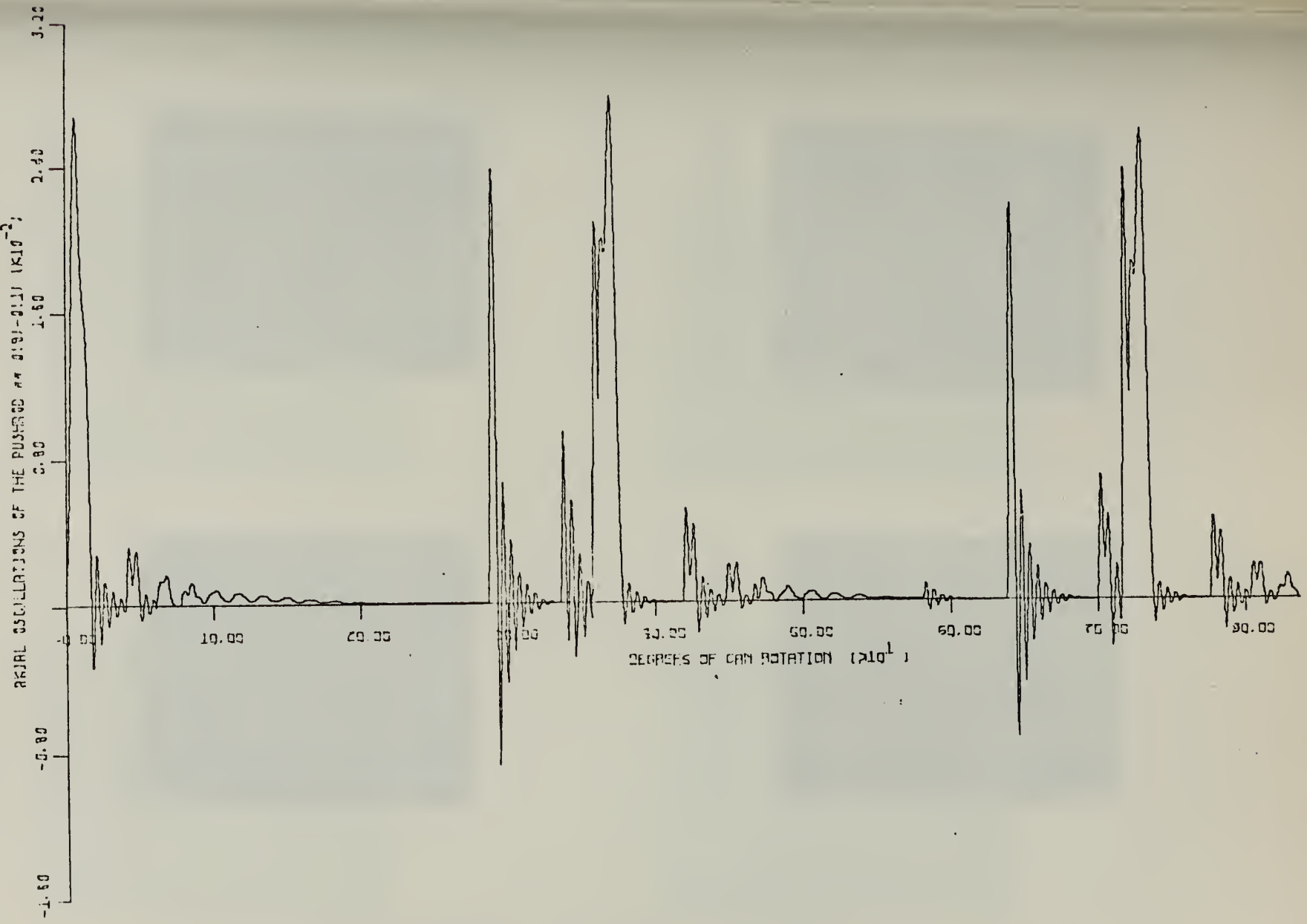


Figure 6.34 THREE CLEARANCES 11,000 RPM VALVE SEAT

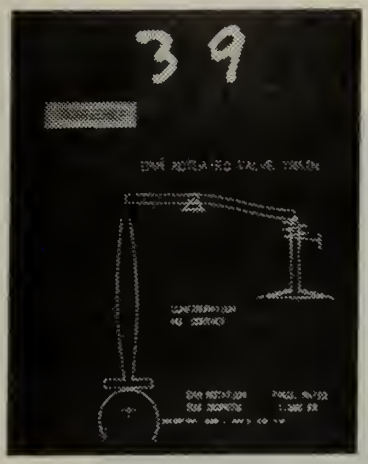


Photo 6.2 - 630 degrees

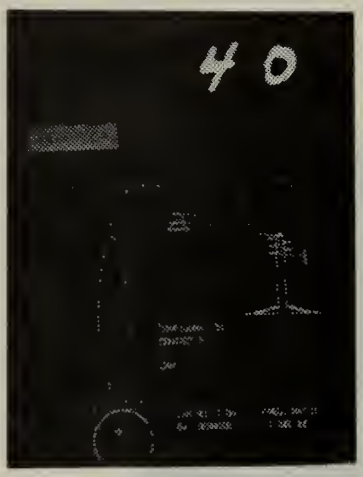


Photo 6.3 - 641 degrees

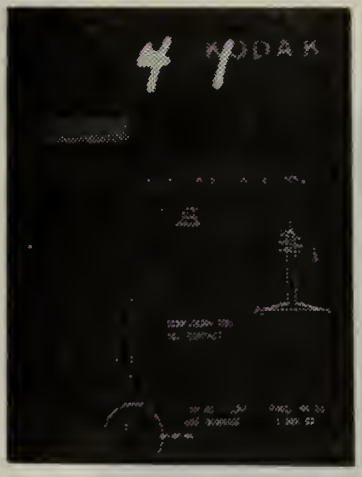


Photo 6.4 - 650 degrees

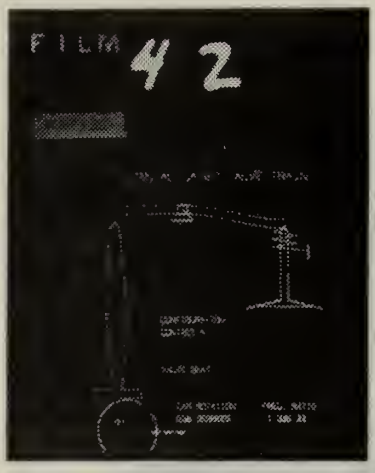


Photo 6.5 - 658 degrees

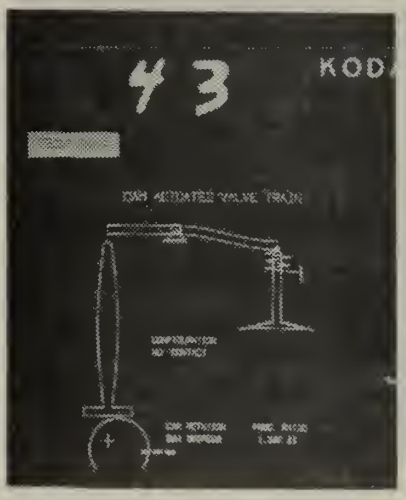


Photo 6.6 - 664 degrees

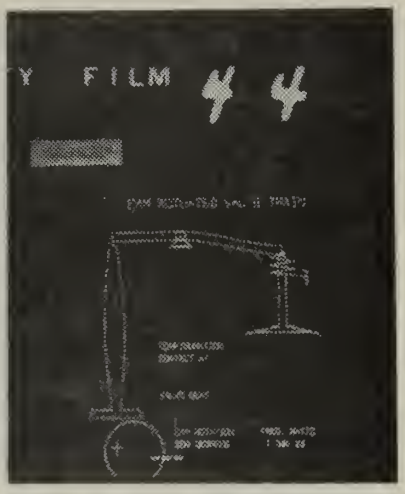


Photo 6.7 - 682 degrees

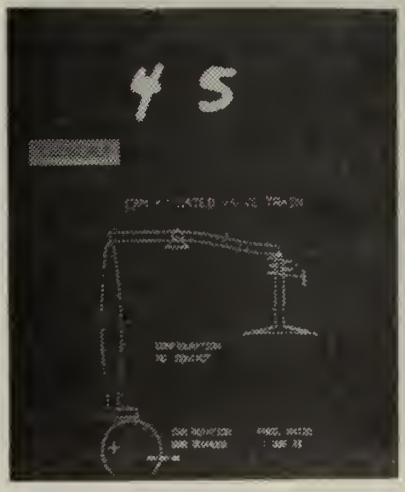


Photo 6.8 - 686 degrees

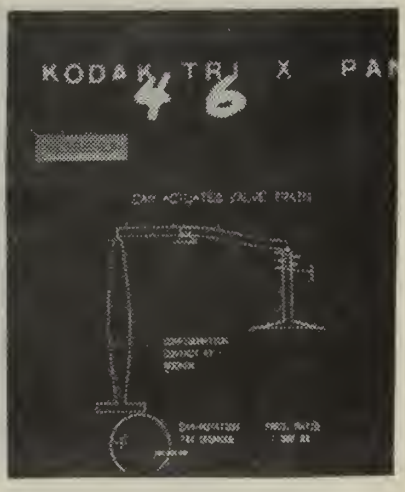


Photo 6.9 - 704 degrees

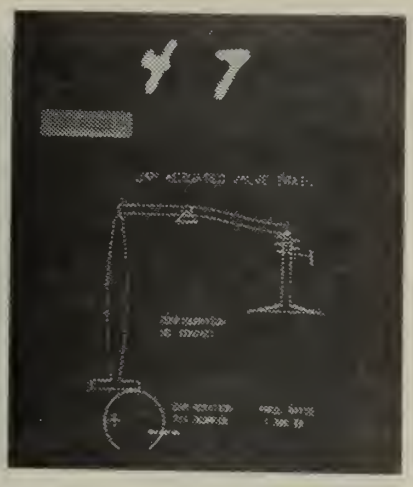


Photo 6.10 - 714 degrees

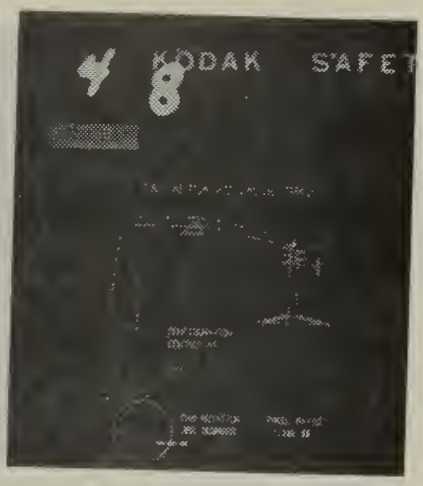


Photo 6.11 - 362 degrees

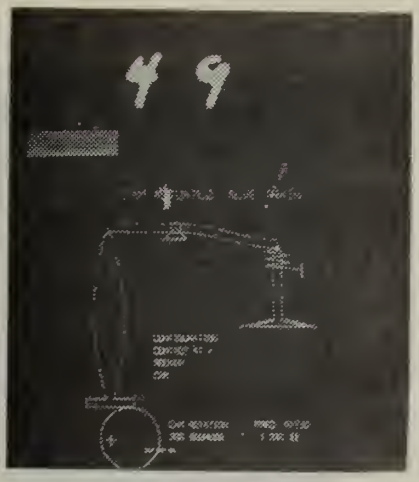


Photo 6.12 - 366 degrees

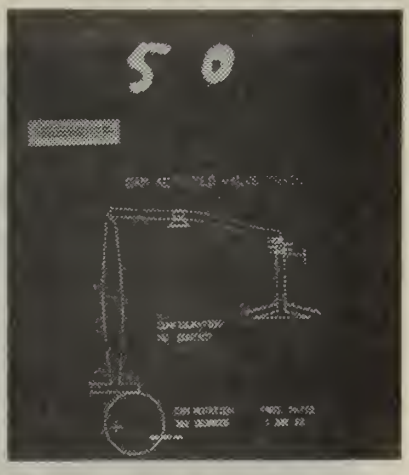


Photo 6.13 - 380 degrees

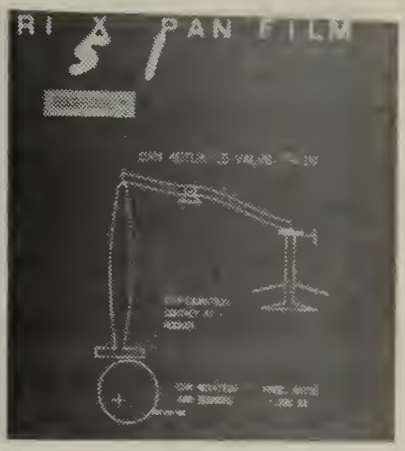


Photo 6.14 - 422 degrees

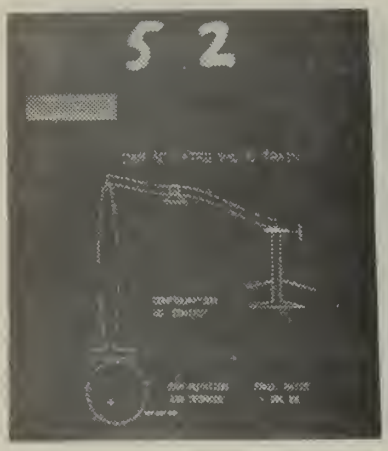


Photo 6.15 - 432 degrees

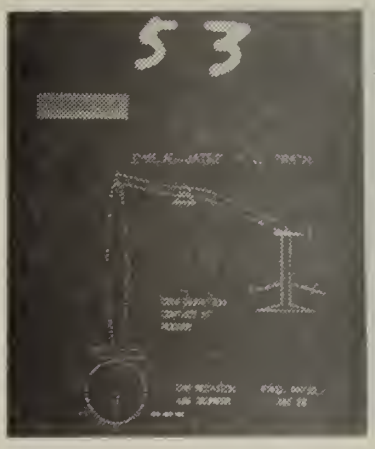


Photo 6.16 - 456 degrees

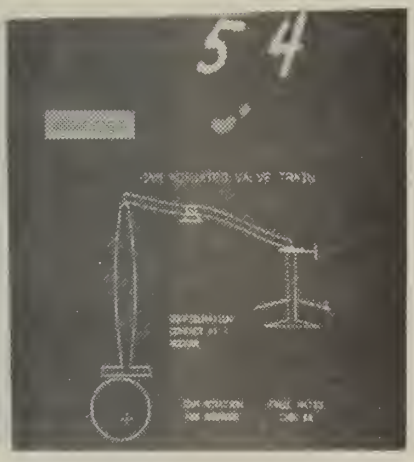


Photo 6.17 - 468 degrees

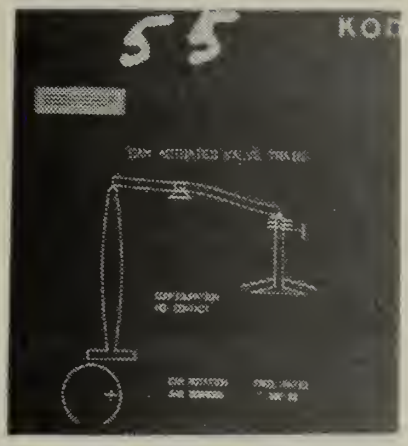


Photo 6.18 - 546 degrees

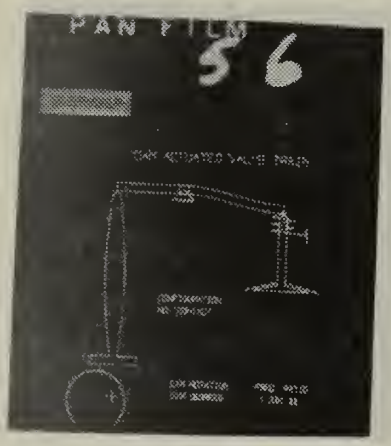


Photo 6.19 - 572 degrees

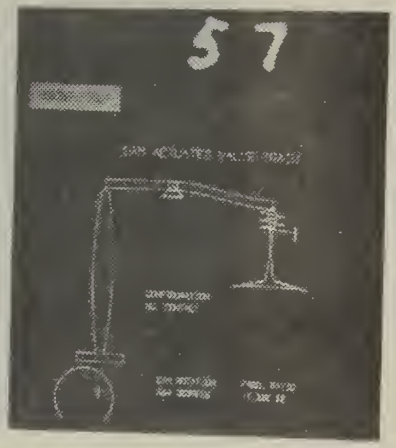


Photo 6.20 - 582 degrees

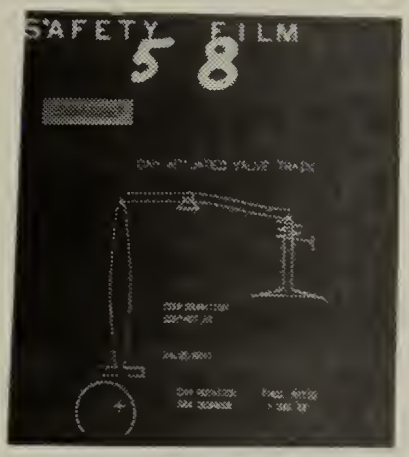


Photo 6.21 - 584 degrees

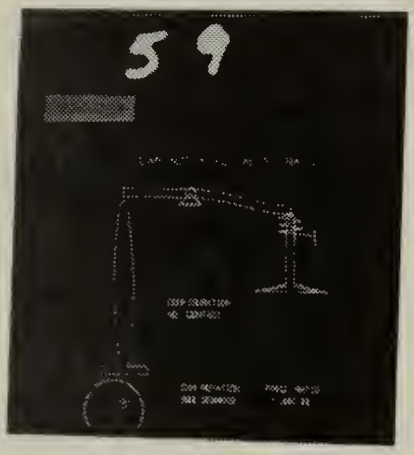


Photo 6.22 - 600 degrees

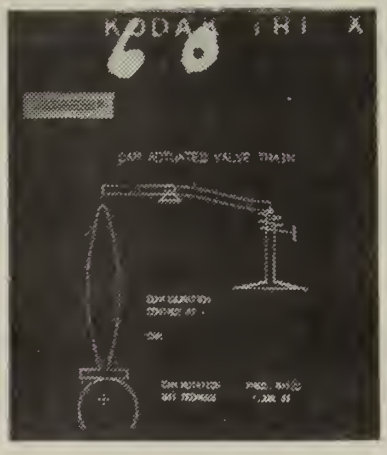


Photo 6.23 - 641 degrees

2. Example 1B, Three Clearances, 11,000 RPM, No Valve Seat

This analysis starts at 274 degrees of cam rotation, point (A). The following figures are utilized for the analysis.

a. Figure 6.35

(1) Displacement difference between cam and pushrod

$(q_1 - q_9) \times 10^{-2}$

(2) Displacement of lower end of pushrod, i.e. follower

$q_1 \times 10^{-1}$

(3) Cam profile, $q_9 \times 10^{-1}$

b. Figure 6.36

(1) Displacement difference between pushrod and rocker

$(q_2 - q_8) \times 10^{-2}$

(2) Displacement difference between cam and pushrod

$(q_1 - q_9) \times 10^{-2}$

c. Figure 6.37 Forces on the pushrod, $F_1 \times 10^3$

d. Figure 6.38 Forces on the rocker, $F_2 \times 10^2$

e. Figure 6.39 Displacement of Valve, $q_7 \times 10^2$

f. Figure 6.40 Axial oscillation of the pushrod,

$(q_8 - q_1) \times 10^{-3}$

Figure 6.40 has been included for completeness and is not annotated.

The following reference points approximately correspond to the indicated degrees of cam rotation, Table 6.2

Reference Point	Degrees of Cam Rotation	Reference Point	Degrees of Cam Rotation
A	274	H	401
B	288	I	413
C	295	J	419
D	314	K	449
E	358	L	581
F	364	AA	634
G	382		

Table 6.2 Graph Reference Points and Degrees of Cam Rotation For Figures 6.35-6.39.

The analysis is similar to example 1A, except here the motion of the system is not impeded by the valve seat.

At point (A), the cam is at its lowest extreme and is starting to rise. The pushrod is floating between the cam and rocker, with downward motion.

At point (B), the cam and pushrod impact against one another and remain in contact for a short period, (B-C). The rising cam and force of impact create severe oscillations of the pushrod and a bounce occurs. The system remains intact, i.e. contact at the cam and rocker, (C-D). The valve has reached its highest extreme and reverses motion downwards.

At point (D), the pushrod and cam separate. Immediately, contact is also lost at the rocker and the pushrod floats free, (D-E).

At point (E), the rising pushrod now impacts against the rocker. This slows the motion of the pushrod sufficiently for the rising cam to again impact against the rocker, point (F). The system then remains in contact for a short period (F-G).

At point (G), the speed of the cam throws the pushrod clear. Immediately separation also occurs at the rocker - pushrod due to inertial effects. The pushrod floats free for a short time, (G-H), and then bounces at the rocker-pushrod clearance, point (I). The system next reaches its extreme value, point (K), i.e. the cam now with downward motion begins falling away from the pushrod. The valve spring, having reached the maximum extension, reverses the harmonic motion of the valve, upward. The rocker and pushrod are now in contact (J), and both have downward harmonic motion.

Finally, the compression of the valve spring slows the rocker valve assembly until the pushrod loses contact at the rocker and again floats free, point (L).

At point (AA), 634 degrees of cam rotation, the cycle then repeats.

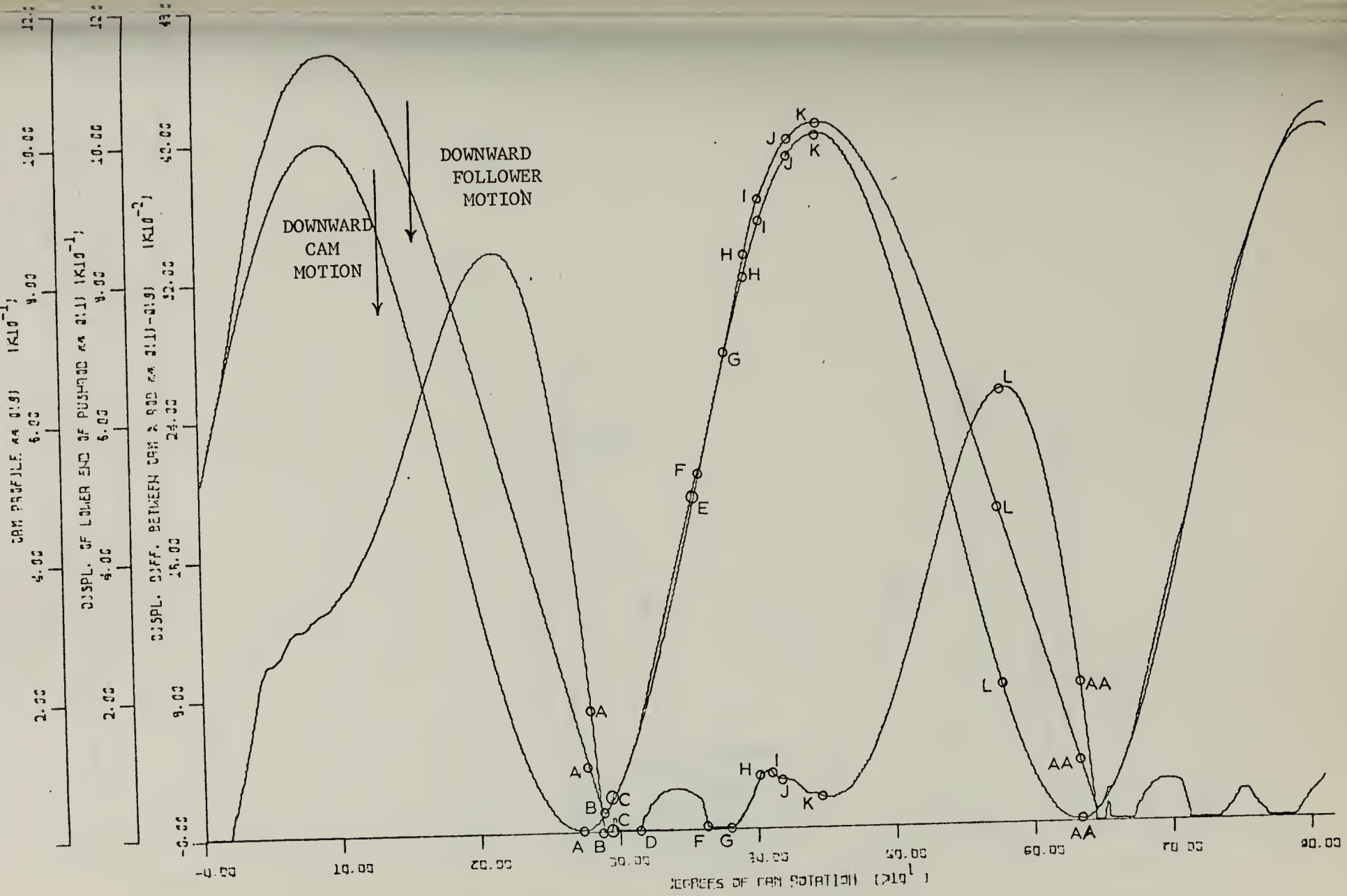


Figure 6.35 THREE CLEARANCES 11,000 RPM NO VALVE SEAT

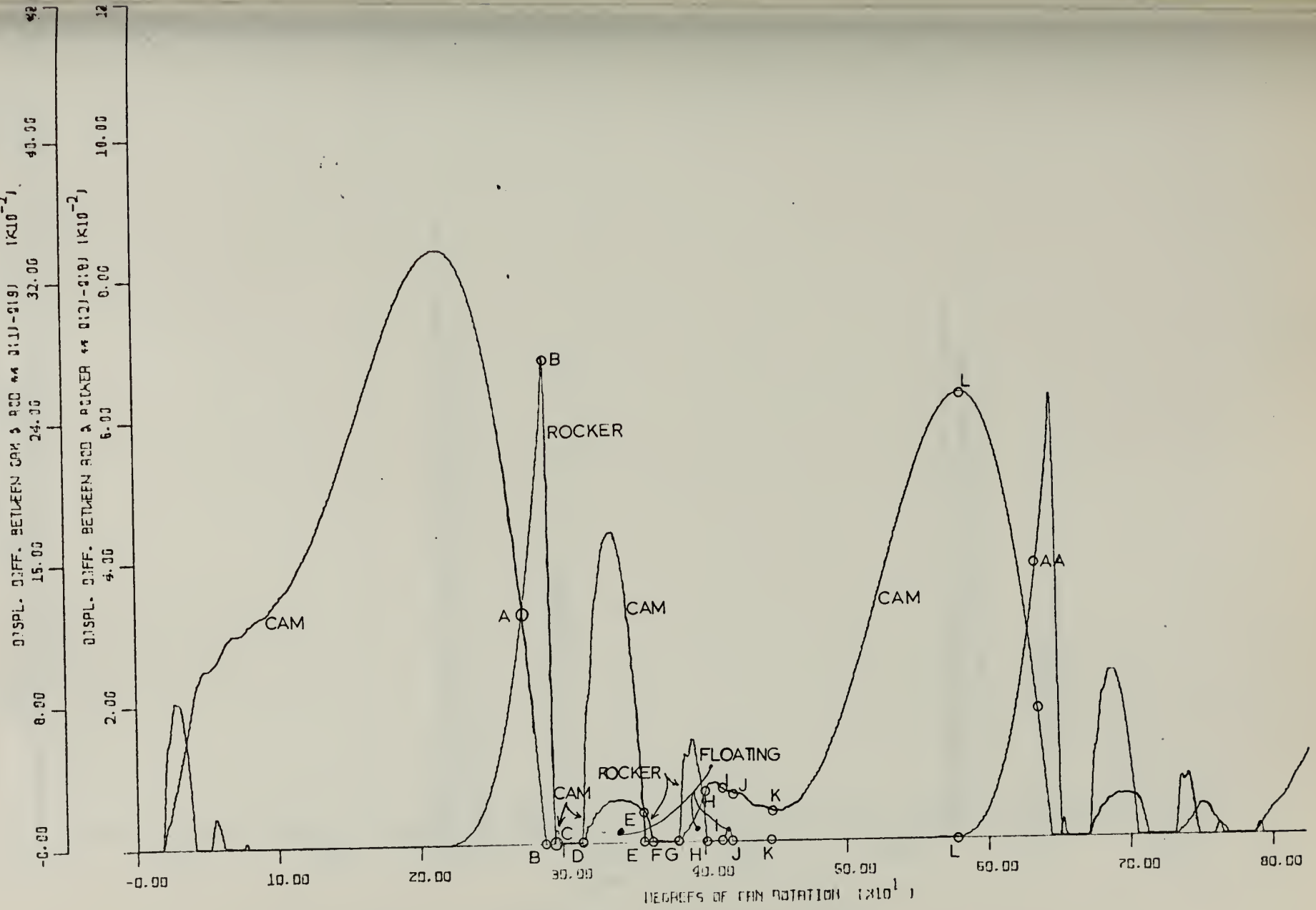


Figure 6.36 THREE CLEARANCES 11,000 RPM NO VALVE SEAT

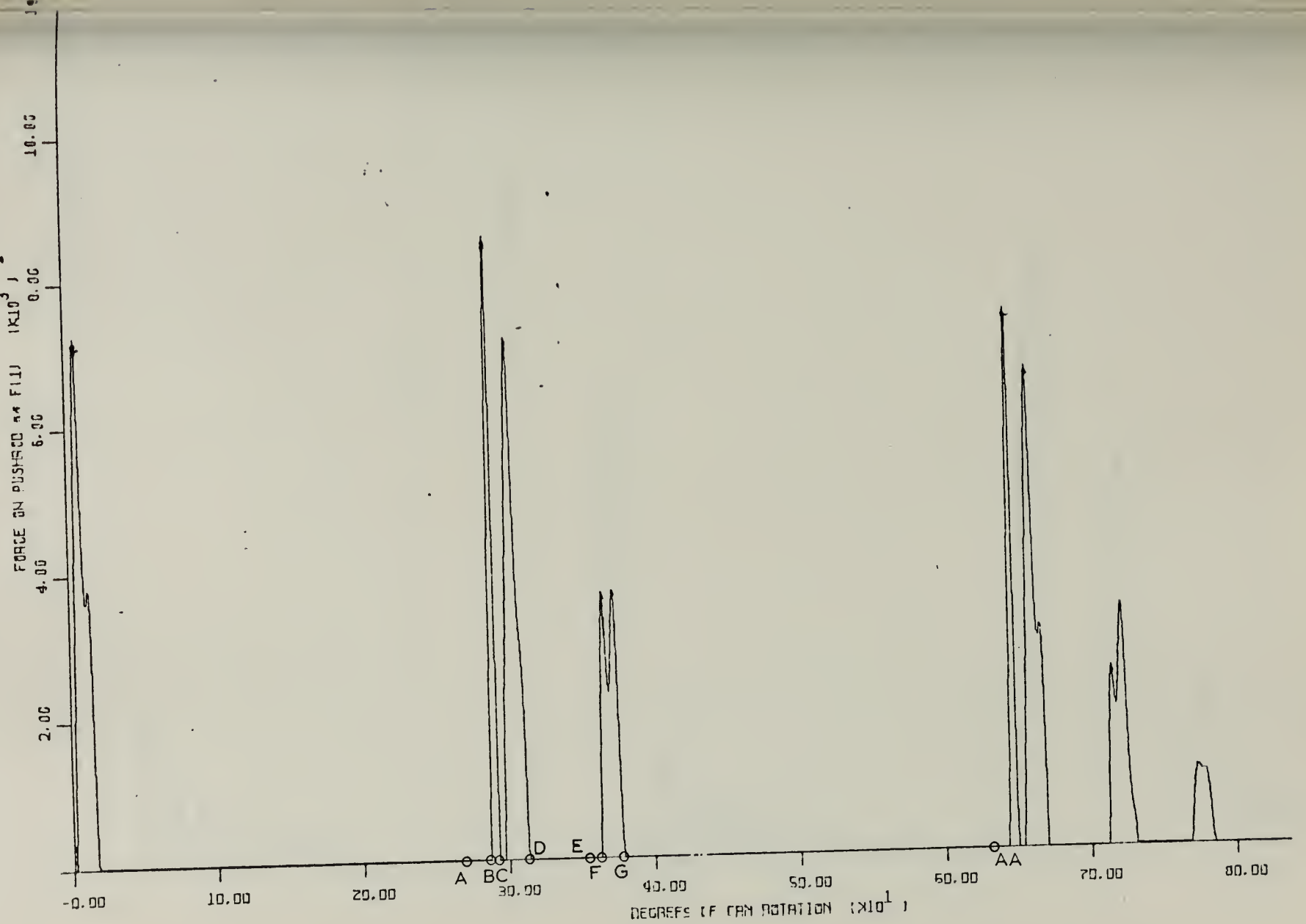


Figure 6.37 THREE CLEARANCES 11,000 RPM NO VALVE SEAT

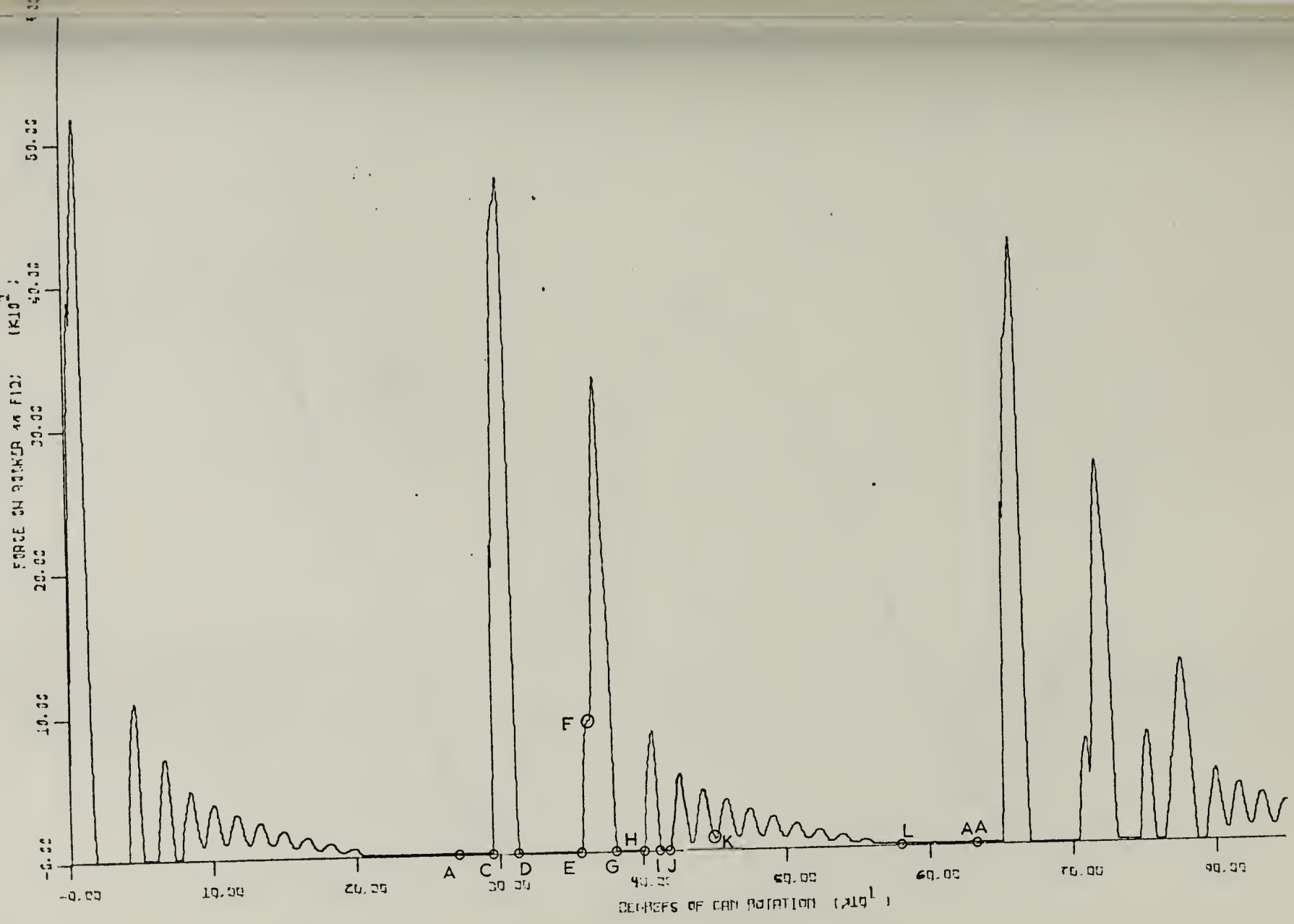


Figure 6.38 THREE CLEARANCES 11,000 RPM NO VALVE SEAT

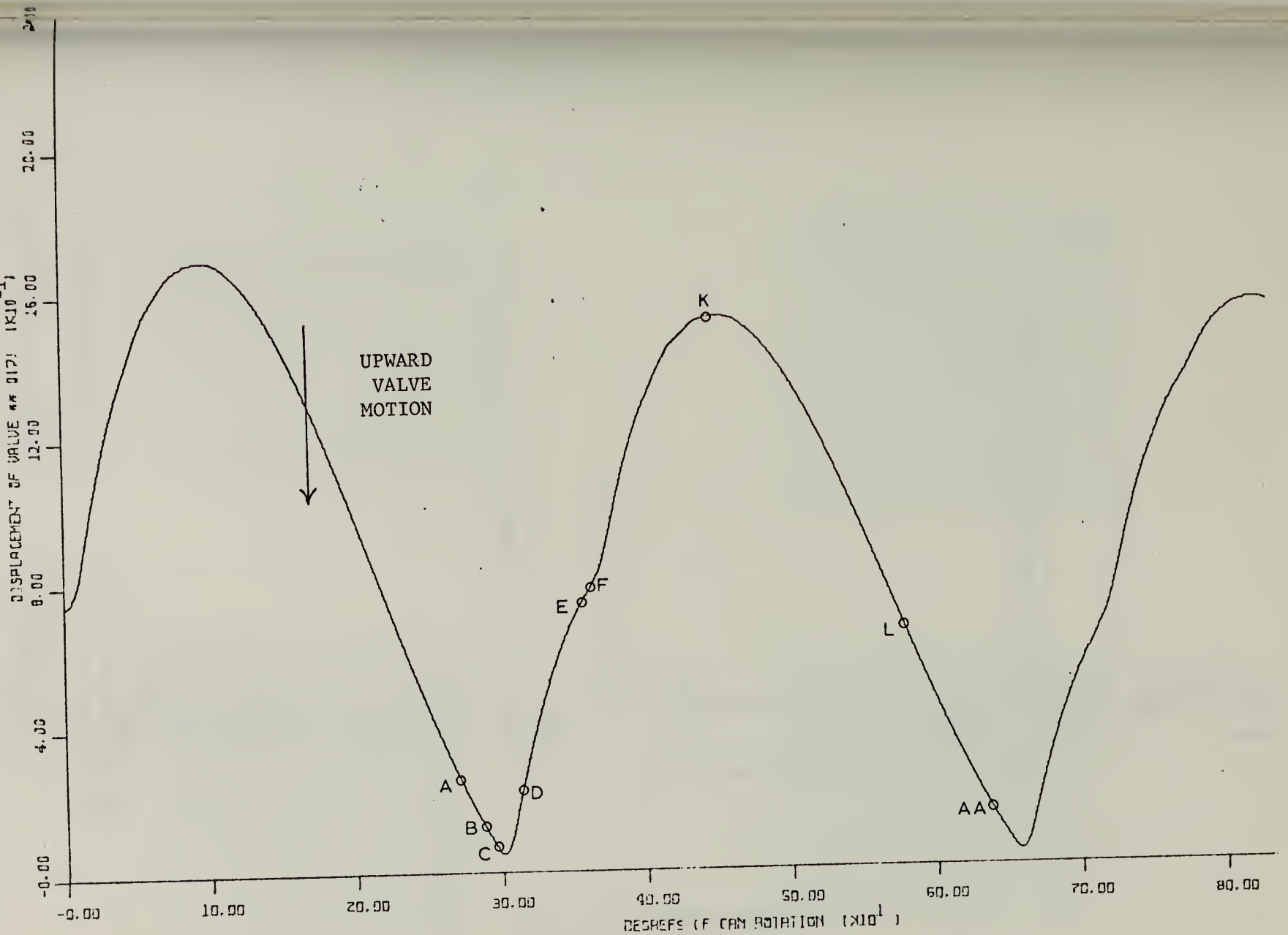


Figure 6.39 THREE CLEARANCES 11,000 RPM NO VALVE SEAT

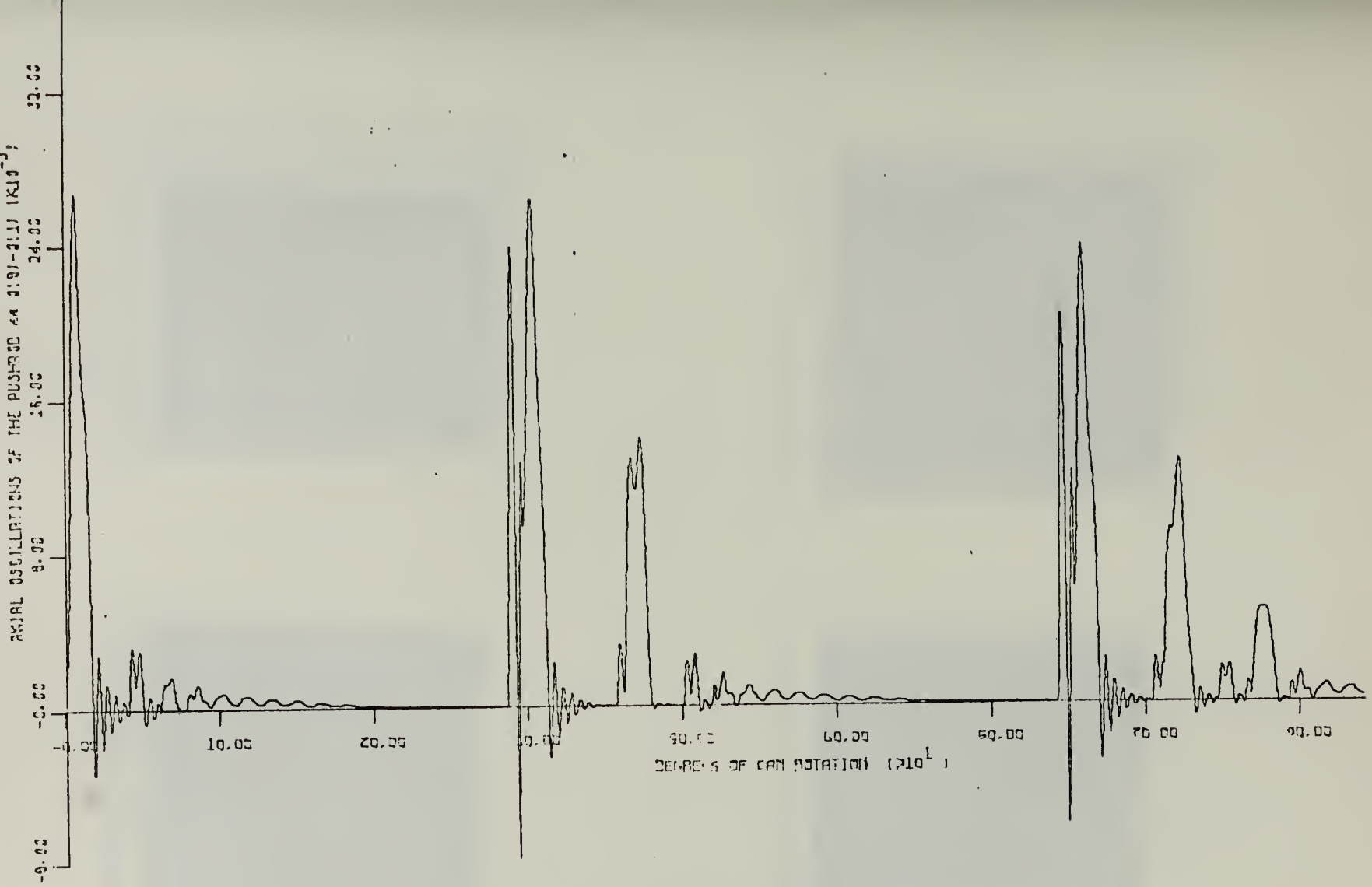


Figure 6.40 THREE CLEARANCES

11,000 RPM NO VALVE SEAT

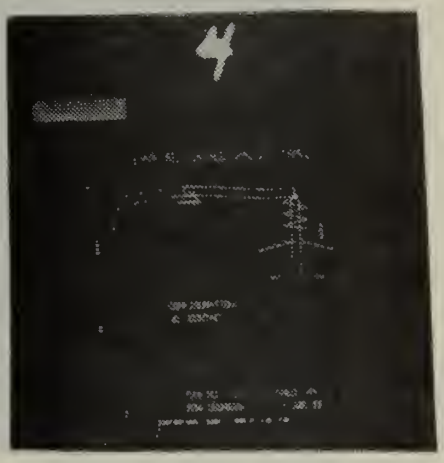


Photo 6.24 - 634 degrees

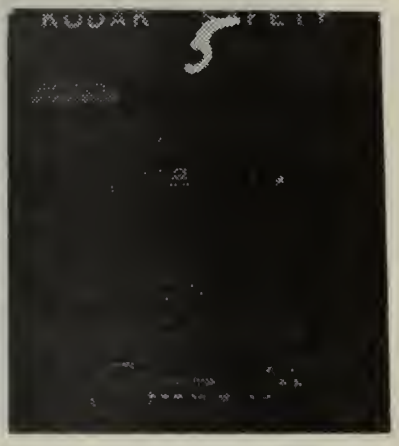


Photo 6.25 - 646 degrees

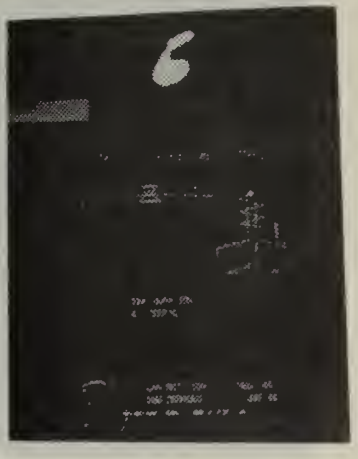


Photo 6.26 - 652 degrees

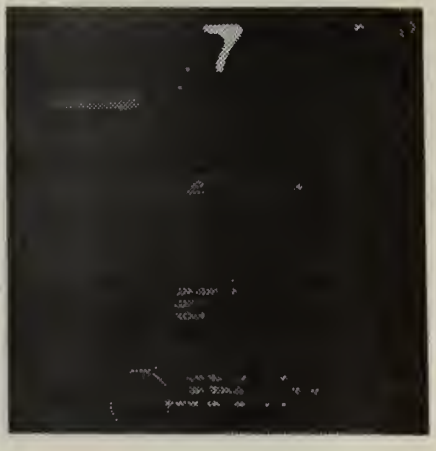


Photo 6.27 - 654 degrees

Photo 6.28 - 658 degrees

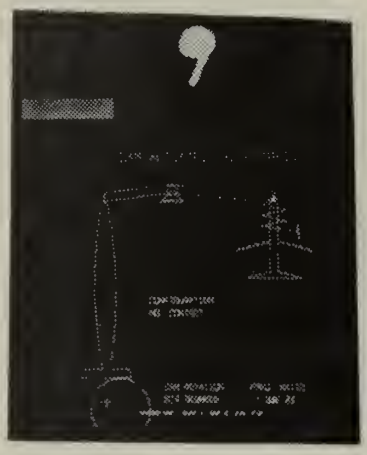


Photo 6.29 - 674 degrees

Photo 6.30 - 708 degrees

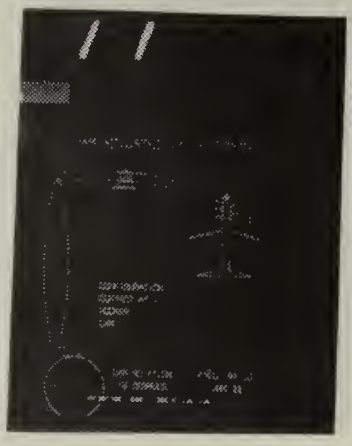


Photo 6.31 - 716 degrees

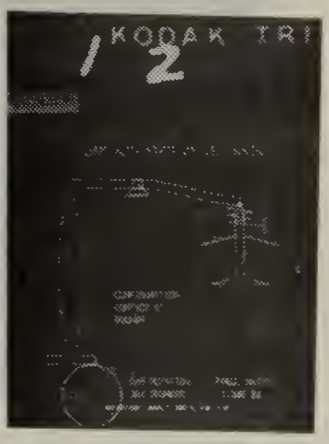


Photo 6.32 - 364 degrees

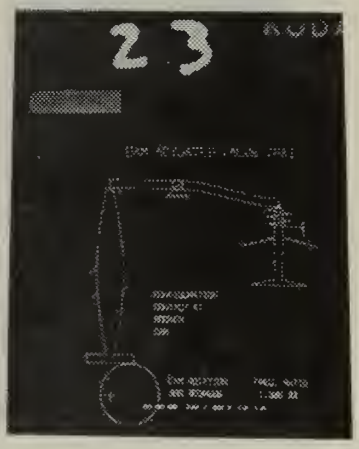


Photo 6.33 - 366 degrees

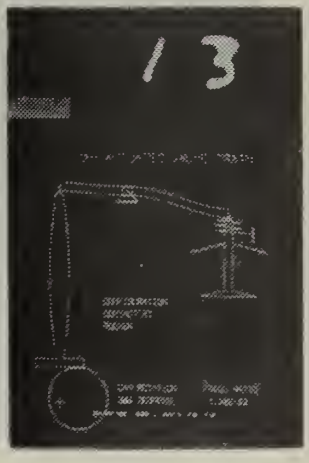


Photo 6.34 - 382 degrees

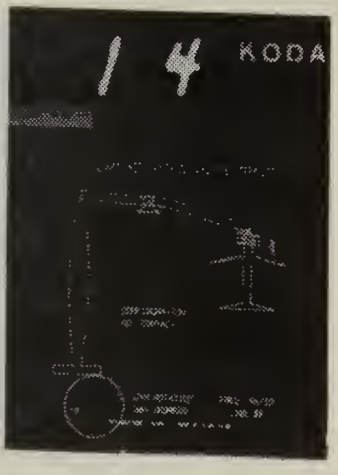


Photo 6.35 - 384 degrees

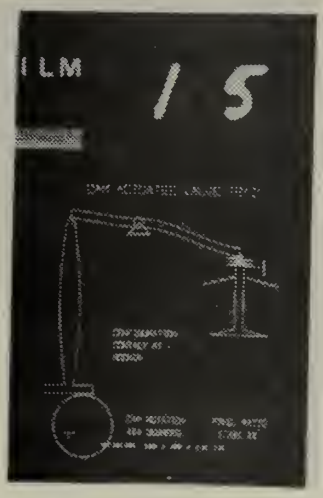


Photo 6.36 - 404 degrees

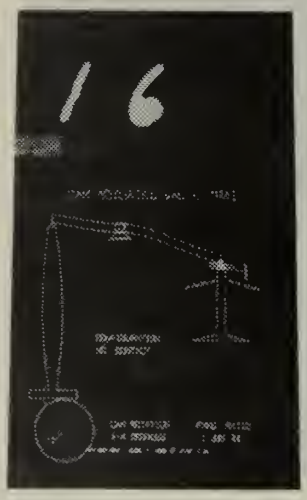


Photo 6.37 - 414 degrees

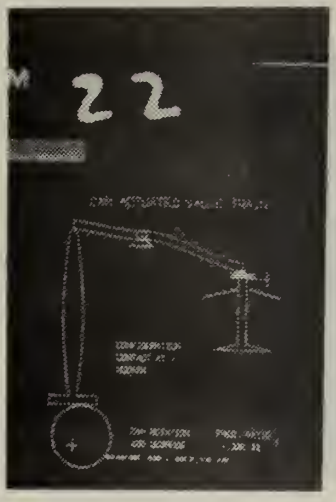


Photo 6.38 - 422 degrees

Photo 6.39 - 450 degrees

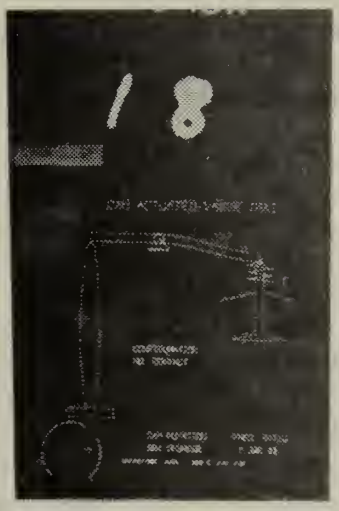


Photo 6.40 - 464 degrees

Photo 6.41 - 572 degrees

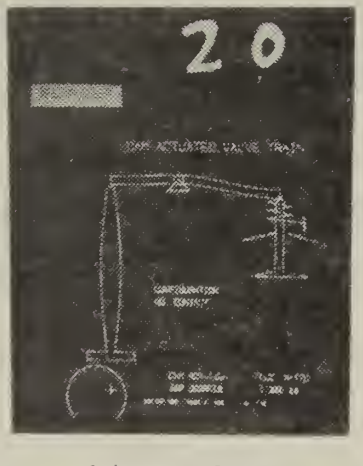


Photo 6.42 - 582 degrees

3. Example 1C, Two Clearances, 11,000 RPM, Valve Seat

This analysis will commence at 333 degrees of cam rotation. One cycle will be discussed, from point (A) to point (AA). The following figures are utilized for the analysis:

a. Figure 6.41 Cam profile and displacement of pushrod, $q_9 \times 10^{-1}$ and $q_1 \times 10^{-1}$

b. Figure 6.42

(1) Cam profile, $q_9 \times 10^{-1}$

(2) Displacement difference between cam and pushrod, $(q_1 - q_9) \times 10^{-2}$

c. Figure 6.43 Force on pushrod, $F_1 \times 10^3$

d. Figure 6.44 Force on the valve, $F_7 \times 10^3$

e. Figure 6.45 Displacement of valve and valve seat, $q_7 \times 10^{-1}$ and $q_{10} \times 10^{-1}$

f. Figure 6.46 Axial oscillation of the pushrod, $(q_8 - q_1) \times 10^{-2}$

g. Figure 6.47 Axial oscillation of the valve stem, $(q_7 - q_6) \times 10^{-3}$

Figures 6.46 and 6.47 have been included for completeness and are not annotated.

The following reference points approximately correspond to the indicated degrees of cam rotation, Table 6.3.

Reference Point	Degrees of Cam Rotation	Reference Point	Degrees of Cam Rotation
A	333	H	600
B	340	I	606
C	379	J	612
D	398	K	681
E	448	L	688
F	467	AA	693
G	483		

Table 6.3 Graph Reference Points and Degrees of Cam Rotation For Figures 6.41 - 6.45

The analysis is similar to that for examples 1A and 1B. For this example the pushrod is pinned to the rocker and thus moves as a part of the system rather than floating free.

At point (A), impact against the pushrod by the cam has just occurred. This has created large system oscillations, first in the pushrod and later in the valve stem. The cam and pushrod are rising. At points (B) and (D) the pushrod is thrown clear of the cam due to its high speed of rotation. At point (E) the cam has reached its highest position and starts to fall. The valve has reached its lowest position and starts its upward travel.

At point (F) the pushrod and rocker come into contact with very little force and travel together for a short distance. Separation again occurs at point (G) when the cam falls away from the pushrod. The valve in its upward travel impacts against the valve seat at point (H). This retards the motion of the pushrod just before contact

at the cam was due to occur (I). The large oscillations created by the valve seating cause the valve to bounce and leave contact at the seat, point (J).

Meanwhile the cam has reached its lowest extreme and begins its upward travel. At point (K) the rising cam impacts against the oscillating pushrod and forces the system to return to its harmonic motion. The cycle then repeats, point (AA).

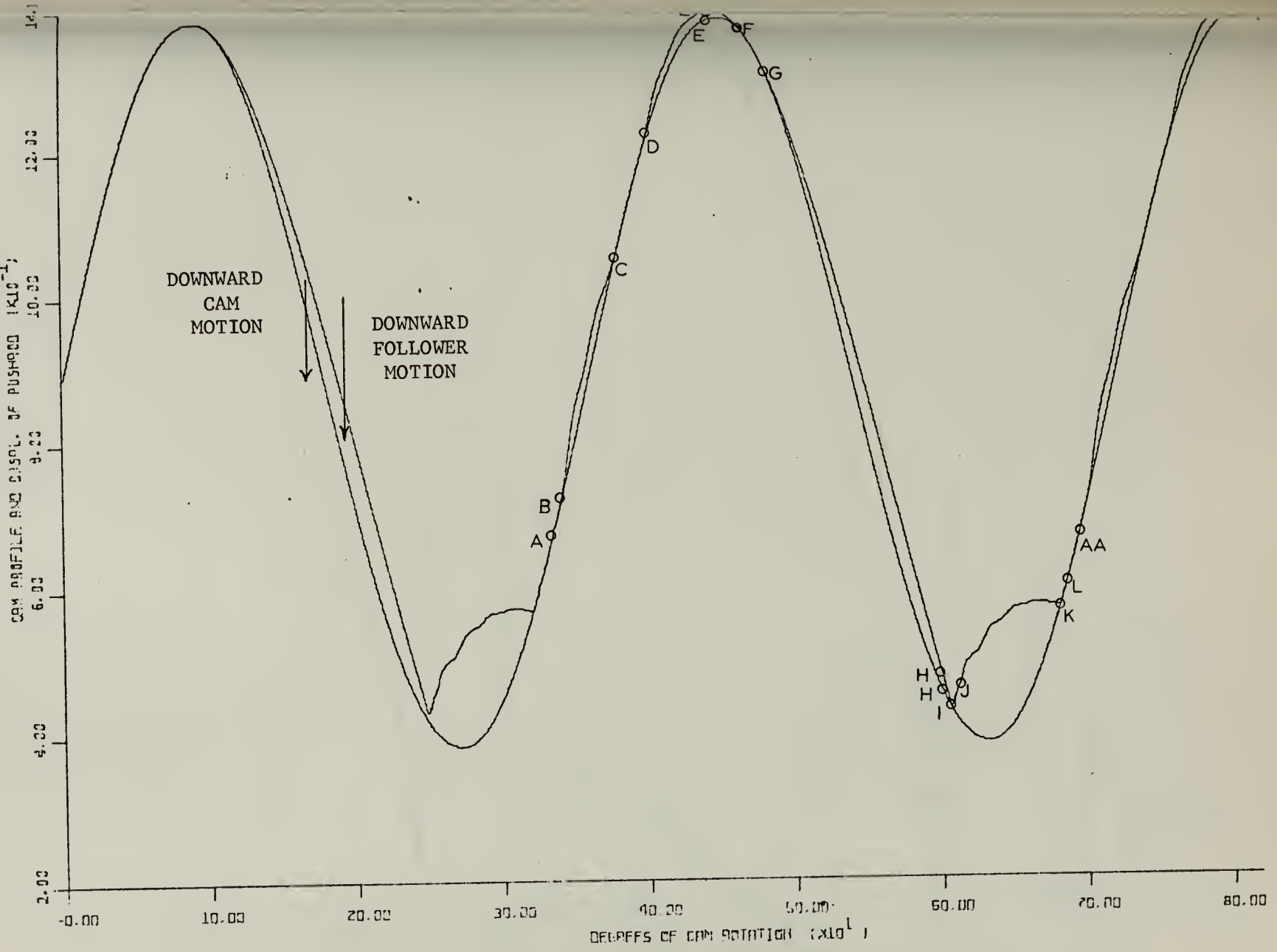


Figure 6.41 TWO CLEARANCES 11,000 RPM VALVE SEAT

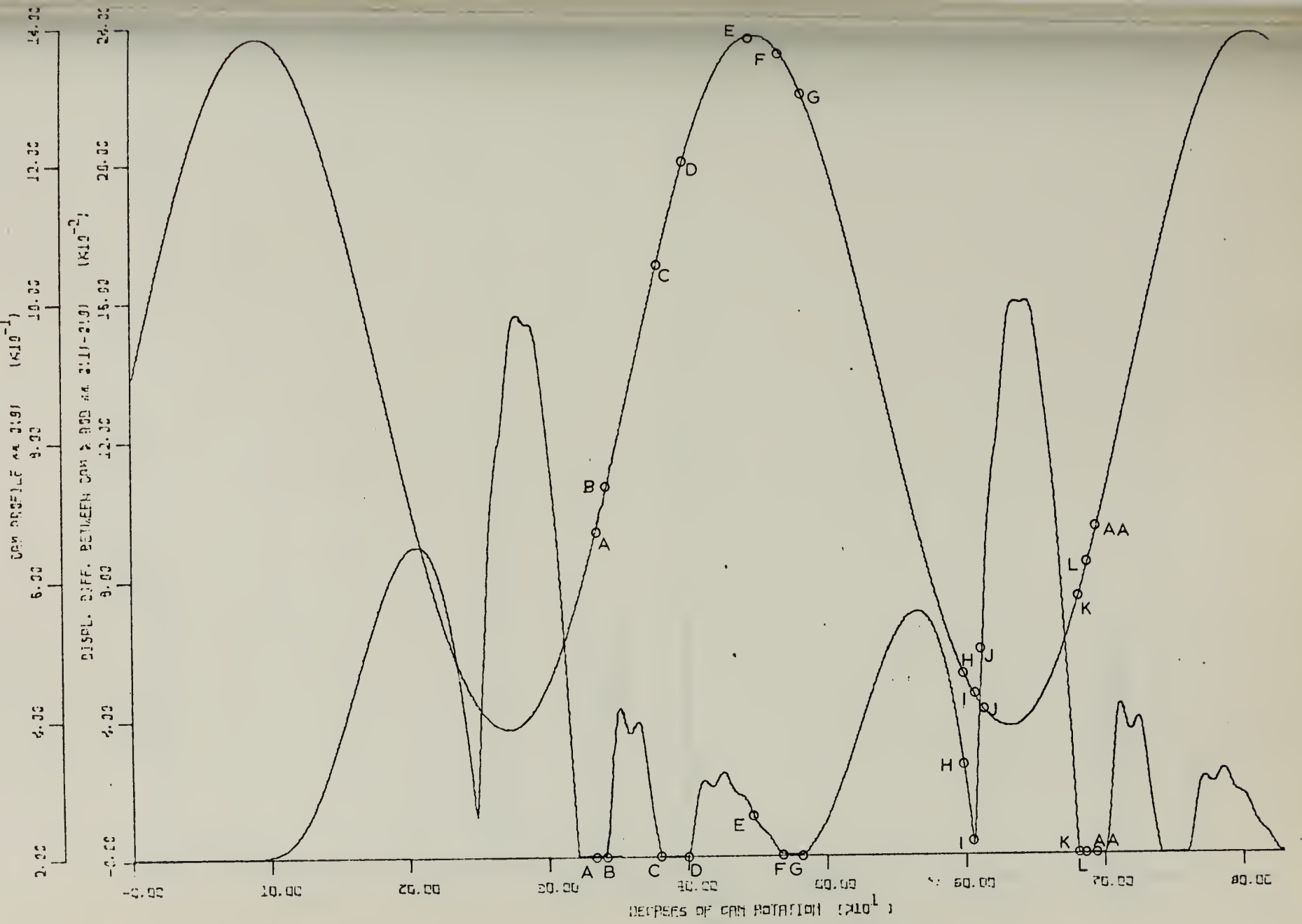


Figure 6.42 TWO CLEARANCES 11,000 RPM VALVE SEAT

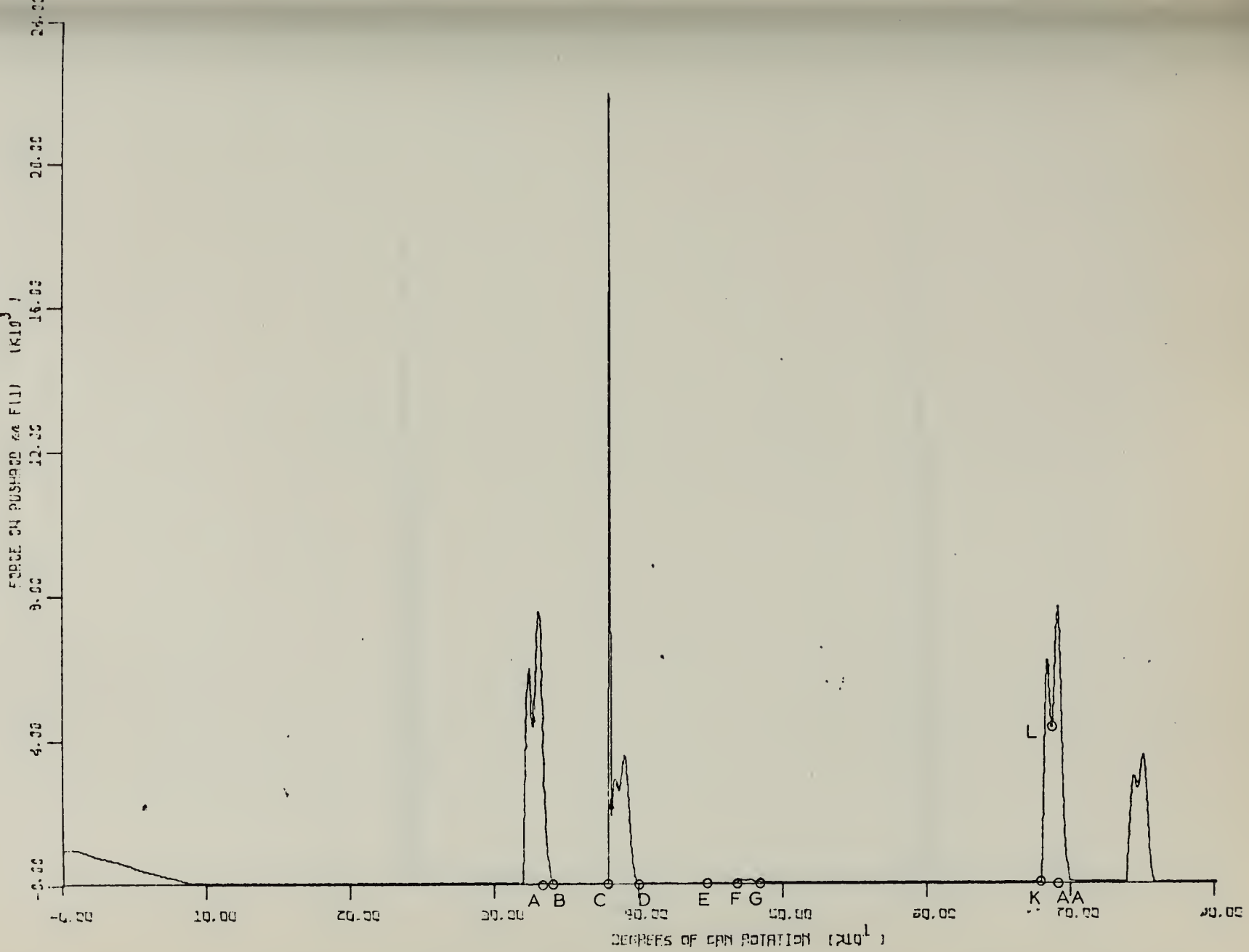


Figure 6.43 TWO CLEARANCES 11;000 RPM VALVE SEAT

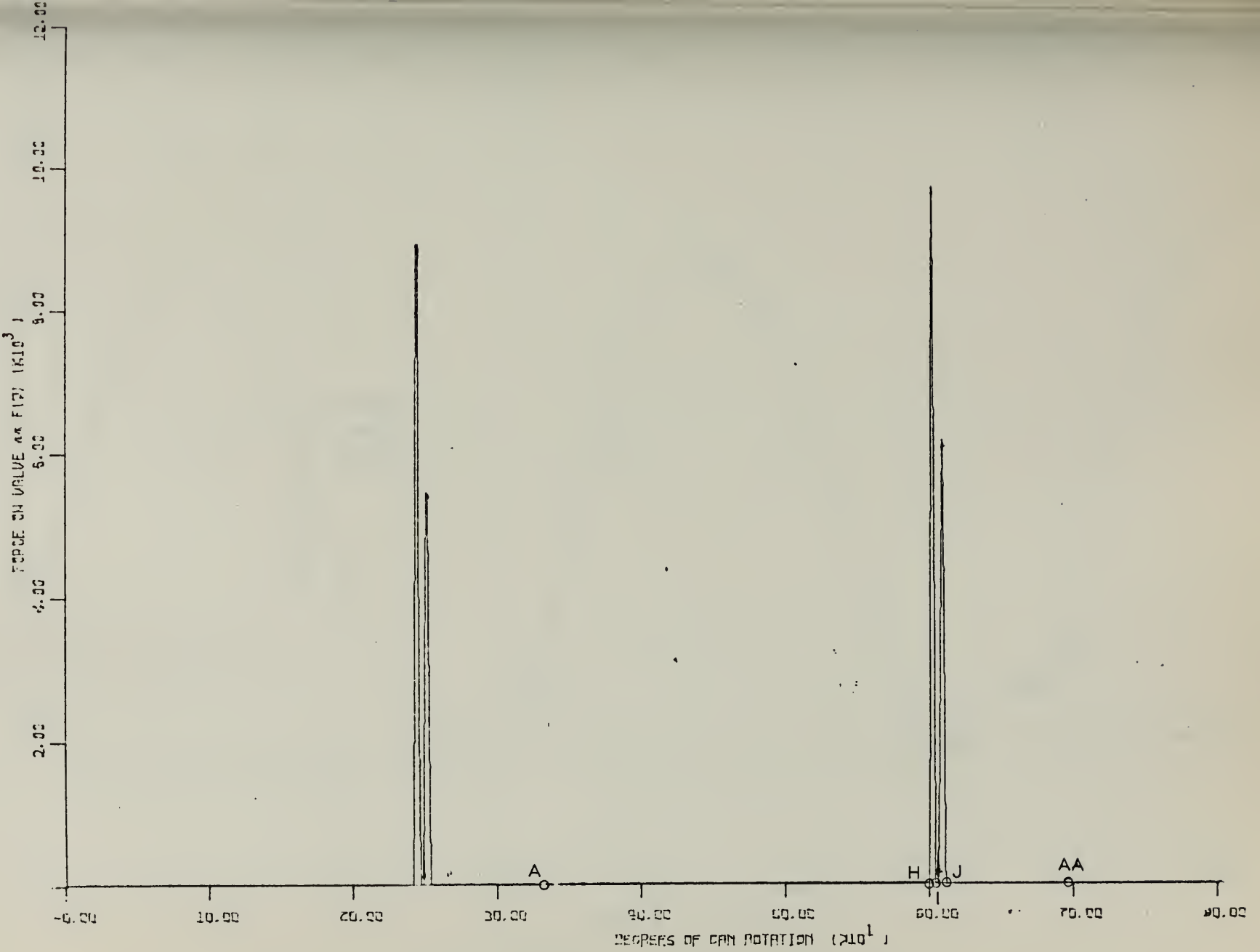


Figure 6.44 TWO CLEARANCES 11,000 RPM VALVE SEAT

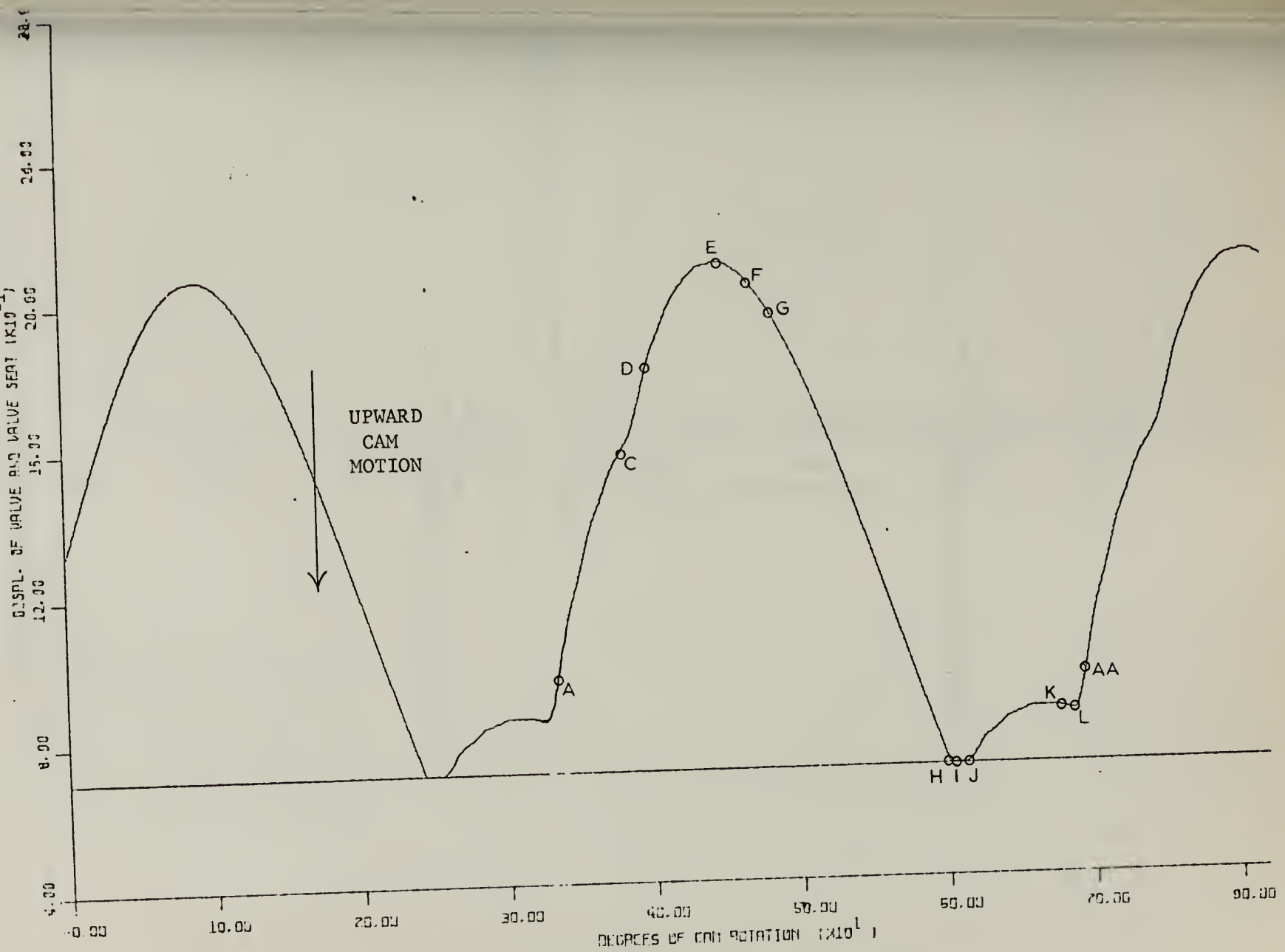


Figure 6.45 TWO CLEARANCES 11,000 RPM VALVE SEAT

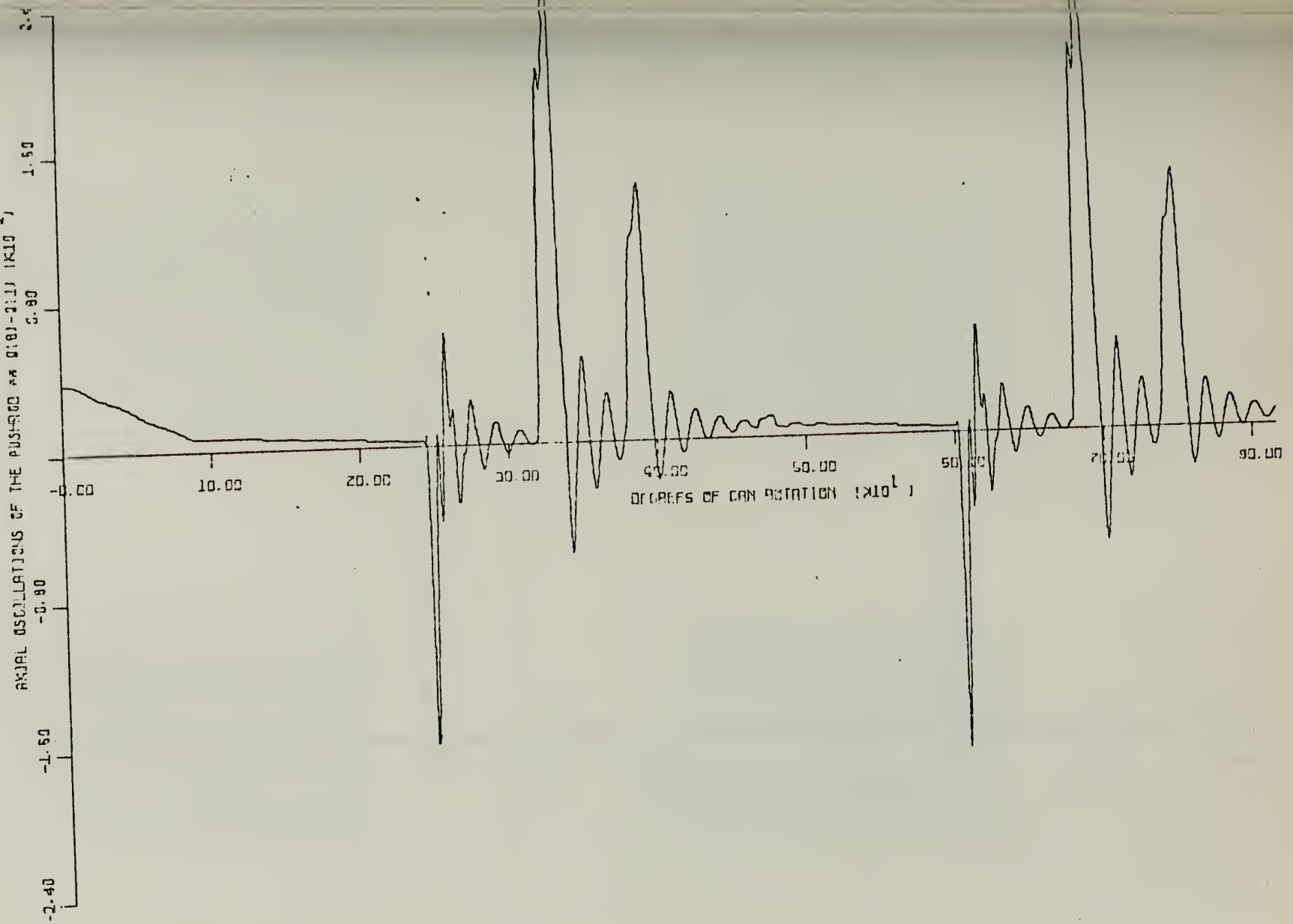


Figure 6.46 TWO CLEARANCES 11,000 RPM VALVE SEAT

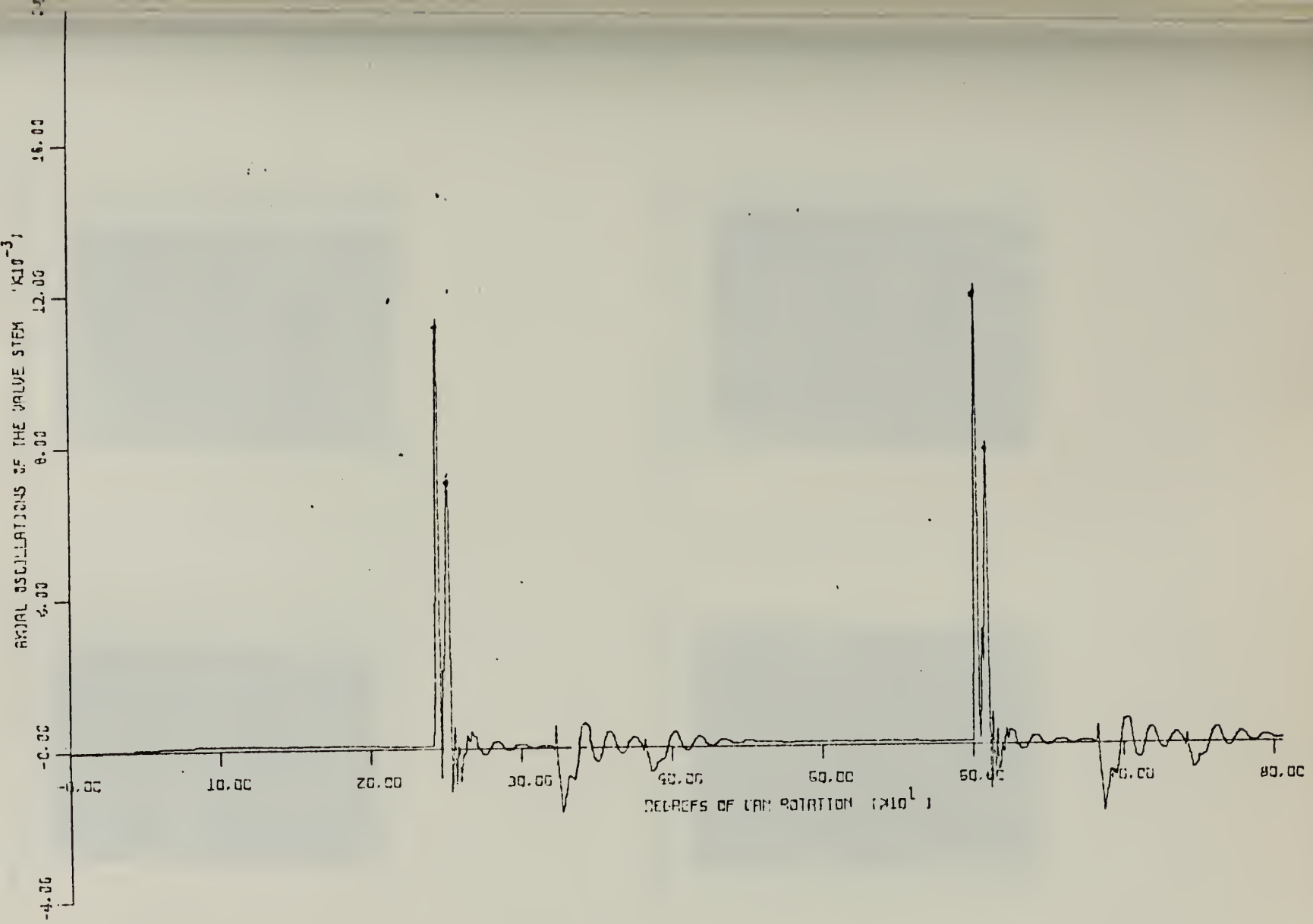


Figure 6.47 TWO CLEARANCES 11,000 RPM VALVE SEAT

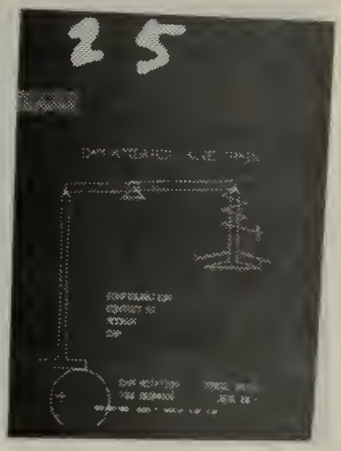


Photo 6.43 - 700 degrees

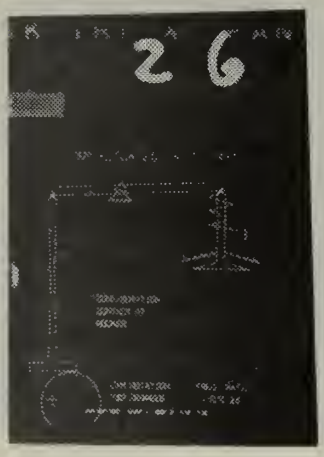


Photo 6.44 - 702 degrees

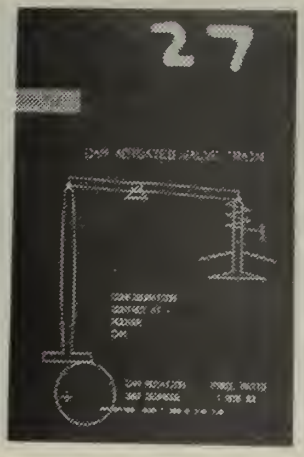


Photo 6.45 - 382 degrees

Photo 6.46 - 400 degrees

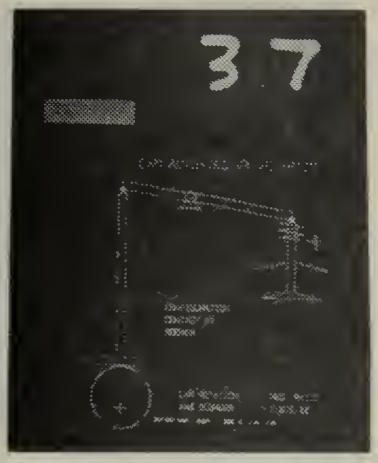


Photo 6.47 - 448 degrees

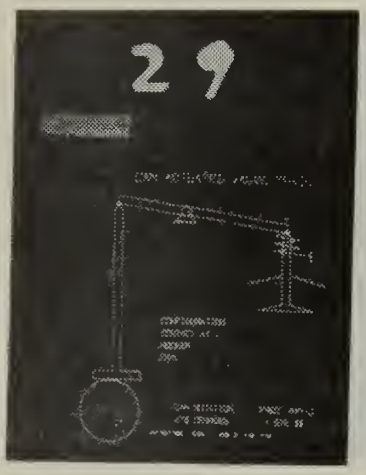


Photo 6.48 - 470 degrees

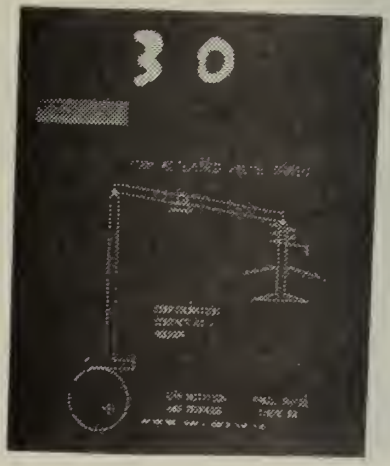


Photo 6.49 - 482 degrees

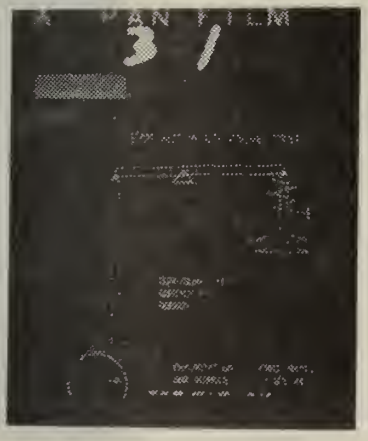


Photo 6.50 - 560 degrees

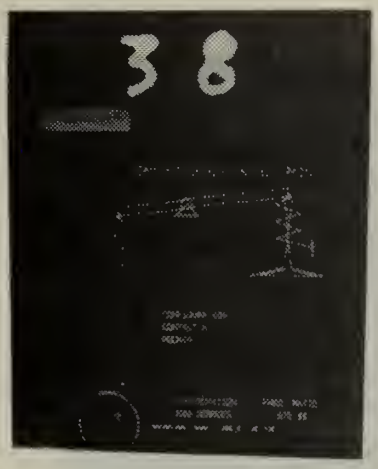


Photo 6.51 - 602 degrees

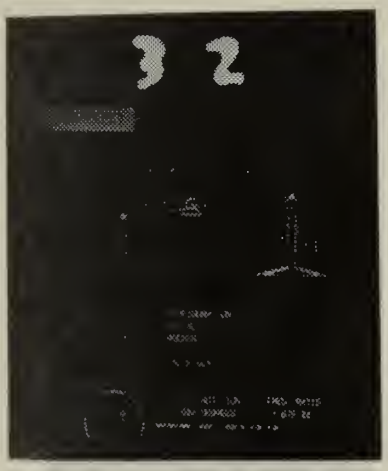


Photo 6.52 - 604 degrees

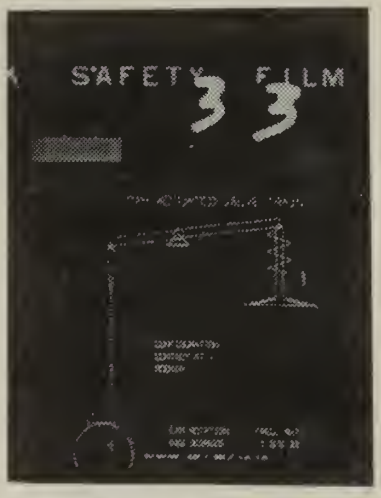


Photo 6.53 - 606 degrees

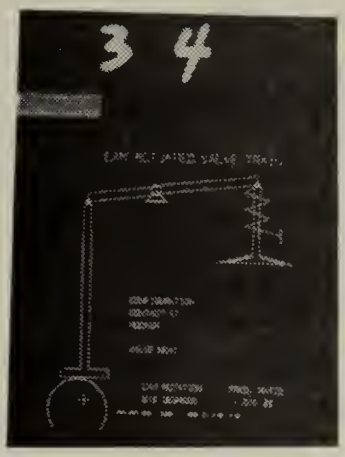


Photo 6.54 - 610 degrees

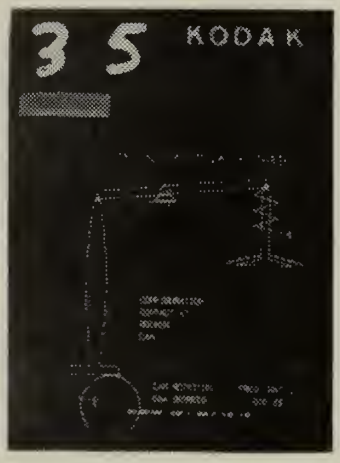


Photo 6.55 - 684 degrees

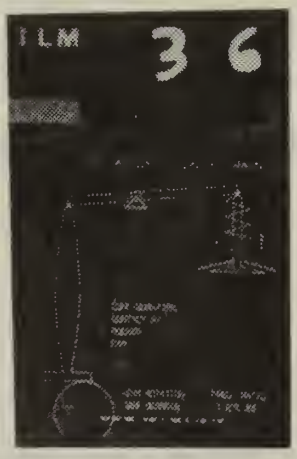


Photo 6.56 - 690 degrees

4. Example 1D, Two Clearances, 11,000 RPM, No Valve Seat

This analysis will commence at 274 degrees of cam rotation, point (A). The following figures are utilized for the analysis.

a. Figure 6.48

(1) Cam profile, $q_9 \times 10^{-1}$

(2) Displacement of lower end of pushrod, $q_1 \times 10^{-1}$

(3) Displacement difference between cam and pushrod, $(q_1 - q_9) \times 10^{-2}$

b. Figure 6.49, Force on pushrod, $F_1 \times 10^3$

c. Figure 6.50, Displacement of valve, $q_7 \times 10^{-1}$

d. Figure 6.51, Axial oscillation of the pushrod, $(q_9 - qq_1) \times 10^{-2}$)

Figure 6.51 has been included for completeness and is not annotated.

The following reference points approximately correspond to the indicated degrees of cam rotation, Table 6.4.

Reference Point	Degrees of Cam Rotation
A	274
B	295
C	314
D	376

Reference Point	Degrees of Cam Rotation
E	398
F	448
AA	634

Table 6.4 Graph Reference Points and Degrees of Cam Rotation For Figures 6.48 - 6.50

The analysis is similar to the above examples. The valve seat position is higher than the maximum excursion of the valve, thus contact does not occur between the seat and valve. The remaining points of interest are then only associated with clearance 1, between pushrod and cam.

At point (A) the cam has reached its lowest extreme and begins rising. The pushrod continues its downward harmonic motion, the valve its harmonic motion upward. At point (B), the rising cam impacts against the pushrod. The motion of the pushrod is reversed. The severe oscillations and inertial effects first insure positive contact and then cause the pushrod and cam to separate, point (C). As the upward motion of the pushrod slows, the rising cam again contacts the pushrod, point (D). Since the motion of these two members is similar, the impact force is not as severe.

At point (E), the speed of cam rotation throws the pushrod off. Harmonic motion of the system then results. The cycle repeats at point (AA).

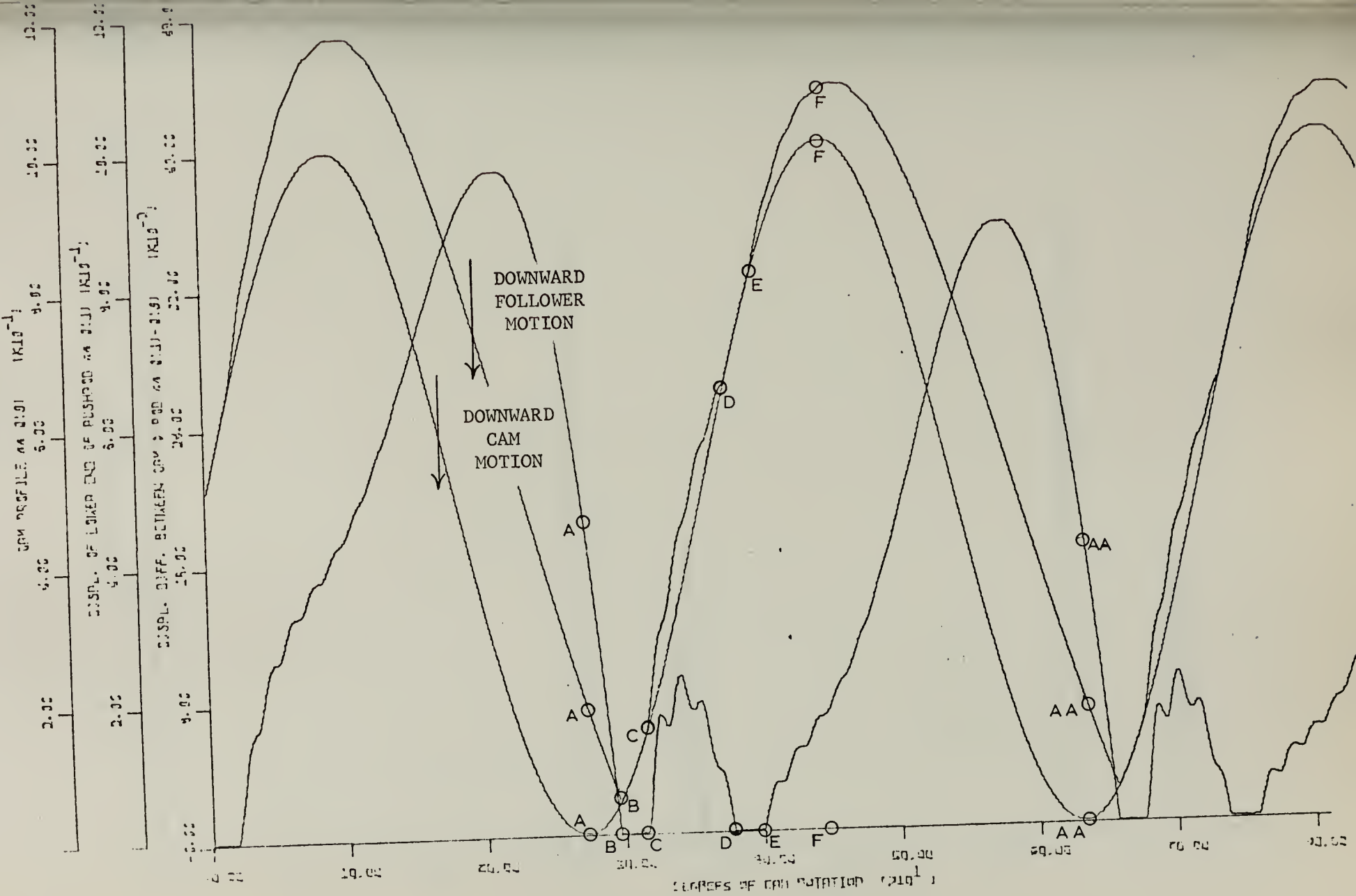


Figure 6.48 TWO CLEARANCES 11,000 RPM NO VALVE SEAT

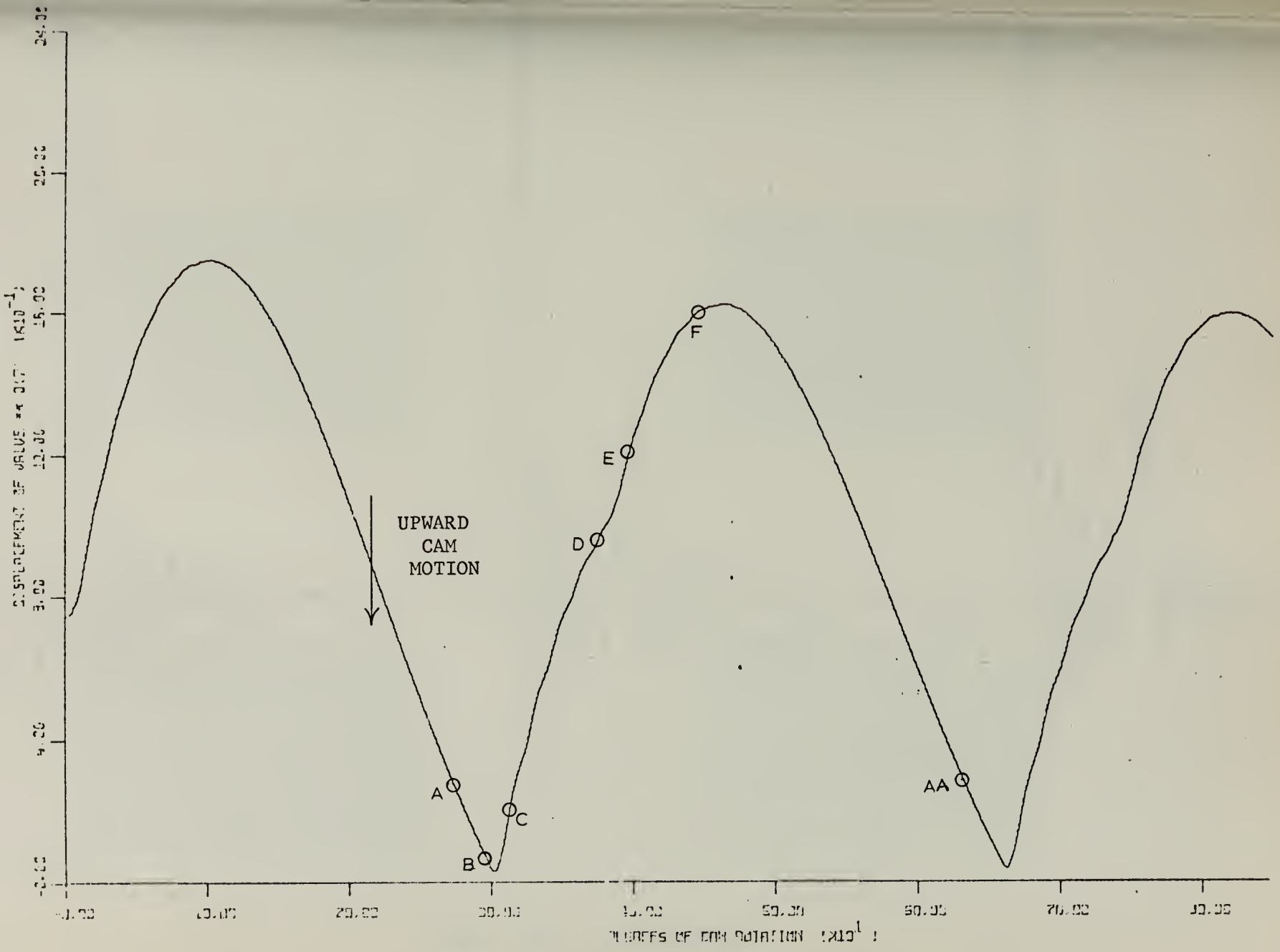


Figure 6.50 TWO CLEARANCES 11,000 RPM NO VALVE SEAT

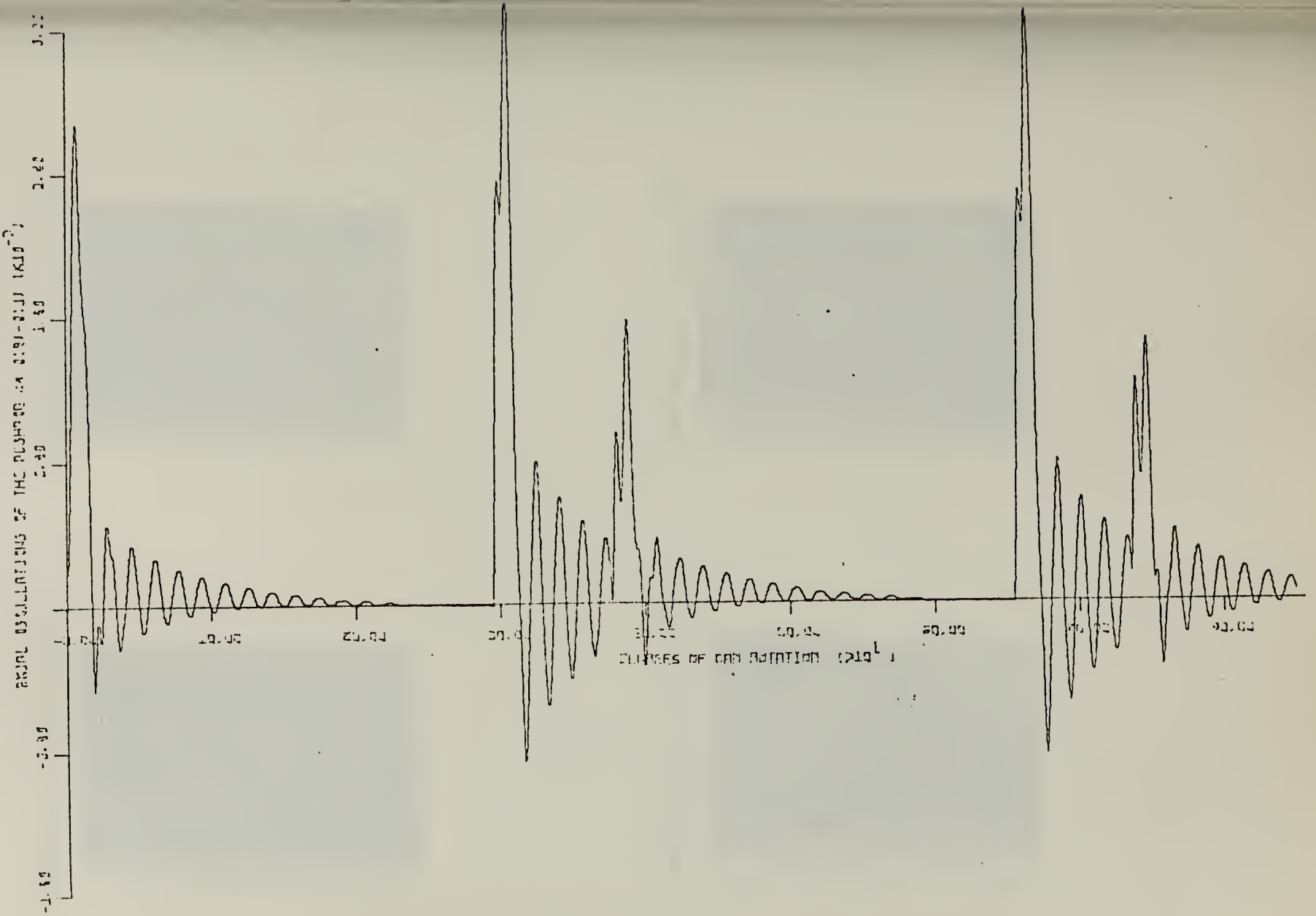


Figure 6.51 TWO CLEARANCES

11,000 RPM NO VALVE SEAT

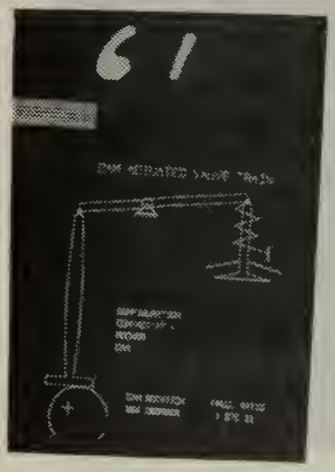


Photo 6.57 - 664 degrees

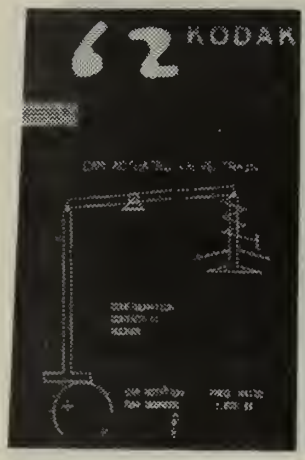


Photo 6.58 - 682 degrees

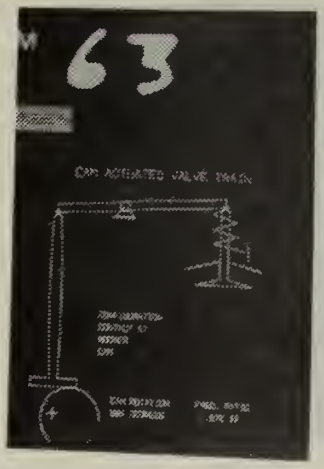


Photo 6.59 - 694 degrees

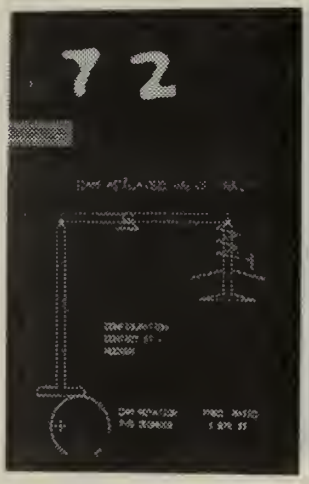


Photo 6.60 - 716 degrees

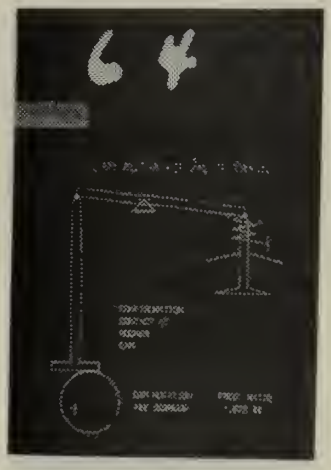


Photo 6.61 - 400 degrees

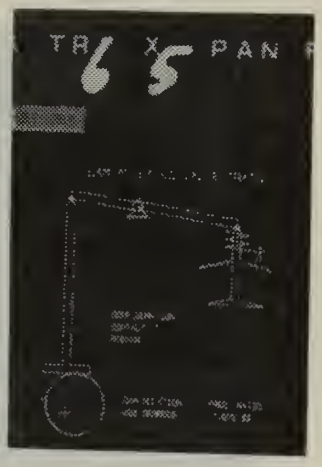


Photo 6.62 - 420 degrees

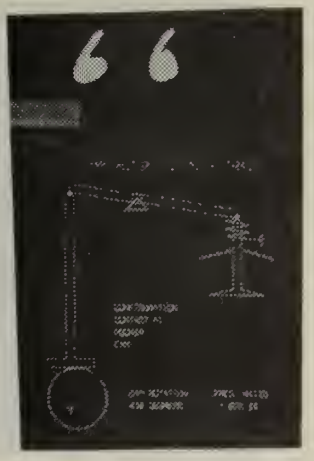


Photo 6.63 - 430 degrees

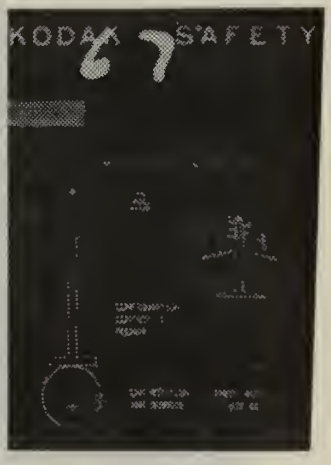


Photo 6.64 - 452 degrees

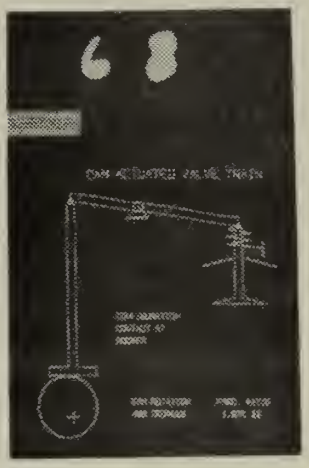


Photo 6.65 - 466 degrees

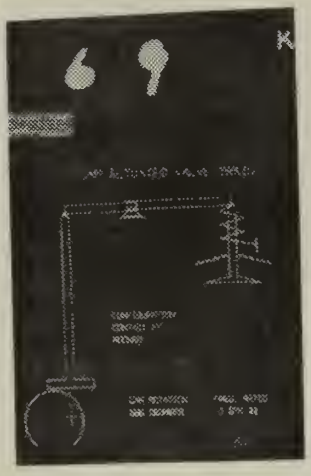


Photo 6.67 - 586 degrees

Photo 6.66 - 600 degrees

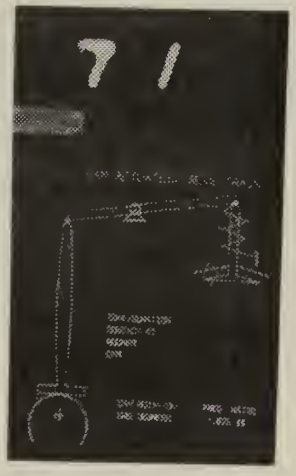


Photo 6.68 - 626 degrees

5. Example two, 9000 RPM and example three, 10,000 RPM were choosen for comparison and completeness of this study. These examples are not annotated and may be found in Appendix F.

VII. CONCLUSION

The simulation for the dynamic response of an elastic link model with three clearances has been described. The algorithm developed is applied to the automobile cam actuated valve train assembly, with external clearances at the valve and cam. The internal clearance at the pushrod-left rocker arm, requires the solution to a second eigenvalue problem in a portion of the calculations. These algorithms are generally coded to allow for application to similar mechanisms. The methods of calculation use address modification arrays to enable application of the program to more complicated models by changing a minimum number of variables and array elements. The numerous subroutines developed have, in general, very specific functions, and are intended to be used as separate calculation packages in a variety of other applications.

While the accuracy of the mathematical model of a mechanism has been greatly increased over the rigid version, the complexity of solution has also increased, even though a number of simplifying assumptions were made. The major assumption made by the theory was that of a linear model so as to permit superposition. Other assumptions, made to simplify the equations but not the theory, involved the choice of coordinates and the use of straight, constant area links.

The purpose of this work was to demonstrate a more accurate model of a mechanism. The extent of this work was to (1) restructure and reprogram an existing simulation to provide for a generalized

method of establishing the physical model configurations; (2) Modify this simulation to allow for more than two clearances; (3) Establish a method for the dynamic graphical display of the model showing the resulting elastic deformations of the model members at high operational speeds. Objectives (1) and (2) are accomplished using the IBM-360 computer for a three clearance simulation. Dynamic dimensioning and program address modifications arrays contribute to the program generalization. Sample problem graphical output is provided. Objective (3) is accomplished with the aid of the ADAGE Graphical Terminal, model 10 interfaced with a Scientific Data System Computer model 9300. Data generated by the IBM computer is tranferred to the SDS computer by punched cards. A program then calculates the model's geometry, position, and deformations. The results are then displayed on the AGT. These results are provided on video tape and may be viewed by requesting NPGS Video Tape 12NPS7200042-VR from the Educational Media Department, Naval Postgraduate School.

It is suggested that additional study be done on the calculation of the pushrod bounce at the rocker. The simulation, as written, has difficulty in obtaining a stable system when contact is regained at this point.

An extension of the AGT system would be to allow for the display of force and displacement curves on the AGT. Methods similar to those developed by this author and Lt. Bowden (Ref. 19) could be conveniently applied.

APPENDIX A

MASS AND STIFFNESS MATRICES

The system mass and stiffness matrices are given by equations (3.6) and (3.7), and are repeated below.

$$[M] = \sum_{i=1}^{5} [\beta]_i^T [M_e]_i [\beta]_i \tag{3.6}$$

$$[K] = \sum_{i=1}^{5} [\beta]_i^T [K_e]_i [\beta]_i \tag{3.7}$$

The transformantion matrix $[\beta]$ is given in equation (3.4) and will not be repeated here. The element stiffness and mass matrices are given by reference (1). For the axial members (pushrod, spring, and valve) they are:

$$[K_e]_i = \frac{E_i A_i}{L_i} \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix} \tag{A.1}$$

$$[M_e]_i = \frac{M_i}{6} \begin{bmatrix} 2 & -1 \\ -1 & 2 \end{bmatrix} \qquad (i=1,4,5) \tag{A.2}$$

The element stiffness and mass matrices for the bending members (left and right arms) are:

$$[K_e]_i = \frac{E_i I_i}{L_i^3} \begin{bmatrix} 12 & -12 & 6L_i & 6L_i \\ -12 & 12 & -6L_i & -6L_i \\ 6L_i & -6L_i & 4L_i^2 & 2L_i^2 \\ 6L_i & -6L_i & 2L_i^2 & 4L_i^2 \end{bmatrix} \tag{A.3}$$

$$[M_e]_i = \frac{M_i}{420} \begin{bmatrix} 156 & 54 & 22L_i & -13L_i \\ 54 & 156 & 13L_i & -22L_i \\ 22L_i & 13L_i & 4L_i^2 & -3L_i^2 \\ -13L_i & -22L_i & -3L_i^2 & 4L_i^2 \end{bmatrix} \quad (i=2,3) \tag{A.4}$$

For equations A.1 through A.4, E_i is the element elastic modulus, A_i is the element cross-sectional area, L_i is the element length, I_i is the element moment of inertia about the bending axis, and M_i is the total element mass of the i^{th} member.

Evaluating equation (3.6) for the five elements of the system yields the full system mass matrix, designated as layer one. The elements of this matrix are given by Figure A.1. Similarly, evaluating equation (3.7) yields the system stiffness matrix. The elements of this matrix are shown in Figure A.2.

$\frac{M_1}{3}$	0	0	0	0	0	0	$\frac{M_1}{6}$
0	$\frac{156\ M_2}{420}$	$\frac{22M_2L_2}{420}$	0	0	$\frac{-13L_2M_2}{420}$	0	0
0	$\frac{22L_2M_2}{420}$	$\frac{4L_2^2M_2}{420}$	0	0	$\frac{-3L_2^2M_2}{420}$	0	0
0	0	0	$\frac{156M_3}{420}+\frac{M_4}{3}+\frac{M_5}{3}$	$\frac{-22L_3M_3}{420}$	$\frac{13L_3M_3}{420}$	$\frac{-M_5}{6}$	0
0	0	0	$\frac{-22L_3M_3}{420}$	$\frac{4L_3^2M_3}{420}$	$\frac{-3L_3^2M_3}{420}$	0	0
0	$\frac{-13L_2M_2}{420}$	$\frac{-3L_2^2M_2}{420}$	$\frac{13L_3M_3}{420}$	$\frac{-3L_3^2M_3}{420}$	$\frac{4L_2^2M_2}{420}$	0	0
0	0	0	$\frac{-M_5}{6}$	0	0	$\frac{M_5}{3}$	0
$\frac{M_1}{6}$	0	0	0	0	0	0	$\frac{M_1}{3}$

Figure A.1 Full System Mass Matrix

$\frac{E_1A_1}{L_1}$	0	0	0	0	0	0	$\frac{-E_1A_1}{L_1}$
0	$\frac{+12E_2I_2}{L_2^3}$	$\frac{6E_2I_2}{L_2^2}$	0	0	$\frac{6E_2I_2}{L_2^2}$	0	0
0	$\frac{6E_2I_2}{L_2^2}$	$\frac{4E_2I_2}{L^2}$	0	0	$\frac{2E_2I_2}{L_2}$	0	0
0	0	0	$\frac{12E_3I_3}{L_3^3}$ $+\frac{E_5A_5}{L_5}$ $+\frac{E_4A_4}{L_4}$	$\frac{-6E_3I_3}{L_3^2}$	$\frac{-6E_3I_3}{L_3^2}$	$\frac{E_5A_5}{L_5}$	0
0	0	0	$\frac{-6E_3I_3}{L_3^2}$	$\frac{4E_3I_3}{L_3}$	$\frac{2E_3I_3}{L_3}$	0	0
0	$\frac{6E_2I_2}{L_2^2}$	$\frac{2E_2I_2}{L_2}$	$\frac{-6E_3I_3}{L_3^2}$	$\frac{2E_3I_3}{L_3}$	$\frac{4E_3I_3}{L_3}$ $+\frac{4E_2I_2}{L_2}$	0	0
0	0	0	$\frac{E_5A_5}{L_5}$	0	0	$\frac{E_5A_5}{L_5}$	0
$\frac{-E_1A_1}{L_1}$	0	0	0	0	0	0	$\frac{E_1A_1}{L_1}$

Figure A.2 Full System Stiffness Matrix

The mass and stiffness matrices are valid for the eight coordinate system, i.e. configuration I, II, V, and VI. When the rocker is in contact with the pushrod, the seven coordinate system is used and the transformation, mass and stiffness revert to those developed by Anderson, reference (2). The reduced system mass and stiffness matrices are shown in Figures A.3 and A.4, respectfully. These reduced matrices are stored in layer 3 and are used for configurations III, IV, VII, and VIII.

$\frac{M_1}{3}$	$\frac{-M_1}{6}$	0	0	0	0	0
$\frac{-M_1}{6}$	$\frac{M_1}{3} + \frac{156M_2}{420}$	$\frac{22M_2L_2}{420}$	0	0	$\frac{-13L_2M_2}{420}$	0
0	$\frac{22L_2M_2}{420}$	$\frac{4L_2^2M_2}{420}$	0	0	$\frac{-3L_2^2M_2}{420}$	0
0	0	0	$\frac{156M_3}{420} + \frac{M_4}{3} + \frac{M_5}{3}$	$\frac{-22L_3M_3}{420}$	$\frac{13L_3M_3}{420}$	$\frac{-M_5}{6}$
0	0	0	$\frac{-22L_3M_3}{420}$	$\frac{4L_3^2M_3}{420}$	$\frac{-3L_3^2M_3}{420}$	0
0	$\frac{-13L_2M_2}{420}$	$\frac{-3L_2^2M_2}{420}$	$\frac{13L_3M_3}{420}$	$\frac{-3L_3^2M_3}{420}$	$\frac{4L_2^2M_2}{420}$	0
0	0	0	$\frac{-M_5}{6}$	0	0	$\frac{M_5}{3}$

Figure A.3 Reduced System Mass Matrix

$\frac{E_1A_1}{L_1}$	$\frac{E_1A_1}{L_1}$	0	0	0	0	0
$\frac{E_1A_1}{L_1}$	$\frac{E_1A_1}{L_1}$ $+\frac{12E_2I_2}{L_2^3}$	$\frac{6E_2I_2}{L_2^2}$	0	0	$\frac{6E_2I_2}{L_2^2}$	0
0	$\frac{6E_2I_2}{L_2^2}$	$\frac{4E_2I_2}{L_2}$	0	0	$\frac{2E_2I_2}{L_2}$	0
0	0	0	$\frac{12E_3I_3}{L_3^3}$ $+\frac{E_5A_5}{L_5}$ $+\frac{E_4A_4}{L_4}$	$\frac{-6E_3I_3}{L_3^2}$	$\frac{-6E_3I_3}{L_3^2}$	$\frac{E_5A_5}{L_5}$
0	0	0	$\frac{-6E_3I_3}{L_3^2}$	$\frac{4E_3I_3}{L_3}$	$\frac{2E_3I_3}{L_3}$	0
0	$\frac{6E_2I_2}{L_2^2}$	$\frac{2E_2I_2}{L_2}$	$\frac{-6E_3I_3}{L_3^2}$	$\frac{2E_3I_3}{L_3}$	$\frac{4E_3I_3}{L_3}$ $+\frac{4E_2I_2}{L_2}$	0
0	0	0	$\frac{E_5A_5}{L_5}$	0	0	$\frac{E_5A_5}{L_5}$

Figure A.4 Reduced System Stiffness Matrix

APPENDIX B

NEWMARK'S β PARAMETER METHOD

The one step algorithm developed by Newmark (Ref. 4), is chosen as the numerical integration technique used in the simulation. The β parameter may be changed for an analysis. This time marching technique solves the governing equations of motion by using the following relations:

$$\{\dot{q}\}^{n+1} = \{\dot{q}\}^{n} + \frac{\Delta T}{2}\left(\{\ddot{q}\}^{n} + \{\ddot{q}\}^{n+1}\right) \tag{B.1}$$

and

$$\{q\}^{n+1} = \{q\}^{n} + \Delta T\,\{\dot{q}\}^{n} + \frac{(\Delta T)^2}{2}\{\ddot{q}\}^{n} + \beta\,(\Delta T)^2\left(\{\ddot{q}\}^{n+1} - \{q^{n}\}\right) \tag{B.2}$$

The net effect of the parameter β is to change the form of the variation of acceleration during the time interval ΔT. For this study, β = 1/6, assumes that the acceleration changes linearly from $\{\ddot{q}\}^{n}$ to $\{\ddot{q}\}^{n+1}$, Figure B.1.

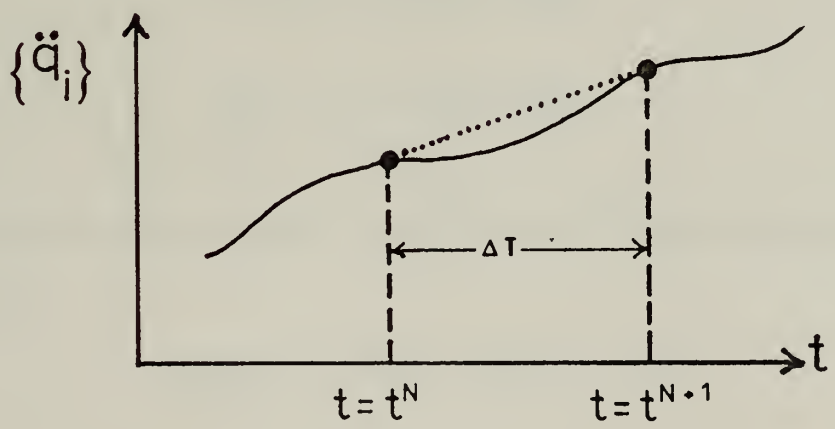


Figure B.1 Time Step Acceleration Curve

In this regard equations B.1 and B.2 are written as:

$$\text{Acceleration} = \ddot{q}_i(t) = \ddot{q}_i^n + \frac{(\ddot{q}_i^{n+1} - \ddot{q}_i^n)}{\Delta T} t \tag{B.3}$$

$$\text{Velocity} = \dot{q}_i(t) = \dot{q}_i^n + \ddot{q}_i^n t + \frac{(\ddot{q}_i^{n+1} - \ddot{q}_i^n)}{\Delta T} \frac{t^2}{2} \tag{B.4}$$

$$\text{Displacement} = q_i(t) = q_i^n + \dot{q}_i^n t + \ddot{q}_i^n \frac{2}{2} + \frac{(\ddot{q}_i^{n+1} - \ddot{q}_i^n)}{\Delta T} \frac{t^3}{6} \tag{B.5}$$

Evaluate $\dot{q}_i(t)$ and $q_i(t)$ at time $t = \Delta T$,

$$\dot{q}_i^{n+1} = \dot{q}_i^n + \ddot{q}_i^n \frac{\Delta T}{2} + \ddot{q}_i^{n+1} \frac{\Delta T}{2} \tag{B.6}$$

$$q_i^{n+1} = q_i^n + \dot{q}_i^n \Delta T + \ddot{q}_i^n \frac{(\Delta T)^2}{3} + \ddot{q}_i^{n+1} \frac{(\Delta T)^2}{6} \tag{B.7}$$

Let $$\alpha_i^n = \dot{q}_i^n + \ddot{q}_i^n \frac{\Delta T}{2} \tag{B.8}$$

and $$\Psi_i^n = q_i^n + \dot{q}_i^n \Delta T + \ddot{q}_i^n \frac{(\Delta T)^2}{3} \tag{B.9}$$

Now $\dot{q}_i^{n+1}$ and q_i^n can be rewritten:

$$\dot{q}_i^{n+1} = \alpha_i^n + \ddot{q}_i^{n+1} \frac{\Delta T}{2} \tag{B.10}$$

$$q_i^{n+1} = \Psi_i^n + \ddot{q}_i^{n+1} \frac{(\Delta T)^2}{6} \tag{B.11}$$

Substitute the above results for $\dot{q}_i^{n+1}$ and q_i^{n+1} into the equations of motion

$$[M] \{\ddot{q}\} + C \{\dot{q}\} + [K] \{q\} = \{F\} \tag{B.12}$$

$$[M]\{\ddot{q}\}^{n+1} + [C]\{\alpha\}^{n} + \frac{\Delta T}{2}[C]\{\ddot{q}\}^{n+1} + [K]\{\Psi\}^{n} + \frac{(\Delta T)^2}{6}[K]\{\dddot{q}\}^{n+1} = \{P\}^{n+1} \quad \text{(B.13)}$$

Rearranged, $$\left[[M] + \frac{\Delta T}{2}[C] + \frac{\Delta T^2}{6}[K]\right]\{\ddot{q}\}^{n+1} = \{P\}^{n+1} - [C]\{\alpha\}^{n} - [K]\{\Psi\}^{n} \quad \text{(B.14)}$$

Rewritten, $$[\overline{M}]^{n+1}\{\ddot{q}\}^{n+1} = \{\overline{P}\}^{n+1} \quad \text{(B.15)}$$

where $\{P\}^{n+1} = \{F\}$ evaluated at time n+1

$$[\overline{M}]^{n+1} = [M] + \frac{\Delta T}{2}[C] + \frac{\Delta T^2}{6}[K] \quad \text{(B.16)}$$

$$\{\overline{P}\}^{n+1} = \{P\}^{n+1} - [C]\{\alpha\}^{n} - [K]\{\Psi\}^{n} \quad \text{(B.17)}$$

This results in the accelerations $\{\ddot{q}\}^{n+1}$ expressed in terms of the known system values at the prior time step, $t = t^n$.

$$\{\ddot{q}\}^{n+1} = \left[[\overline{M}]^{n+1}\right]^{-1}\{\overline{P}\}^{n+1}$$

APPENDIX C

FOUR CLEARANCE PROBLEM

During the early stages of this study, limited research was conducted on the four clearance problem to better understand the necessary requirements of program generalization procedures. This appendix will present the unique four clearance number scheme that must be used in conjunction with the shifting algorithm presented in section 3.D. Figure C.1 indicates the configuration number associated with the various combinations of clearances, for a given time, that the model is physically permitted to take. Figure C.2 shows the resulting flow diagram. The shift lines relate the flow for a nonpositive force at the clearance indicated. Non-positive displacement differences are along the same shift lines, but in the direction opposite the force arrow.

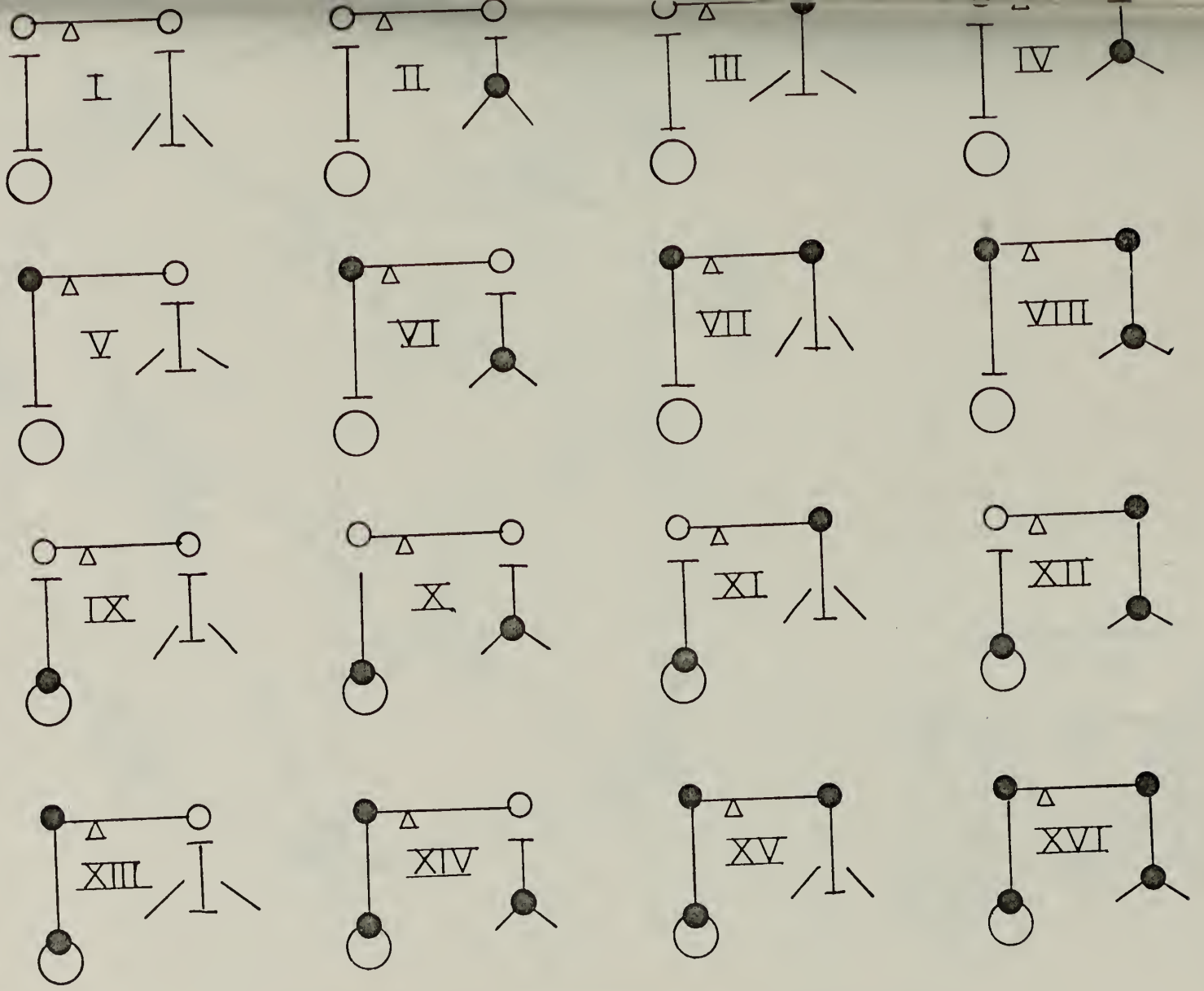
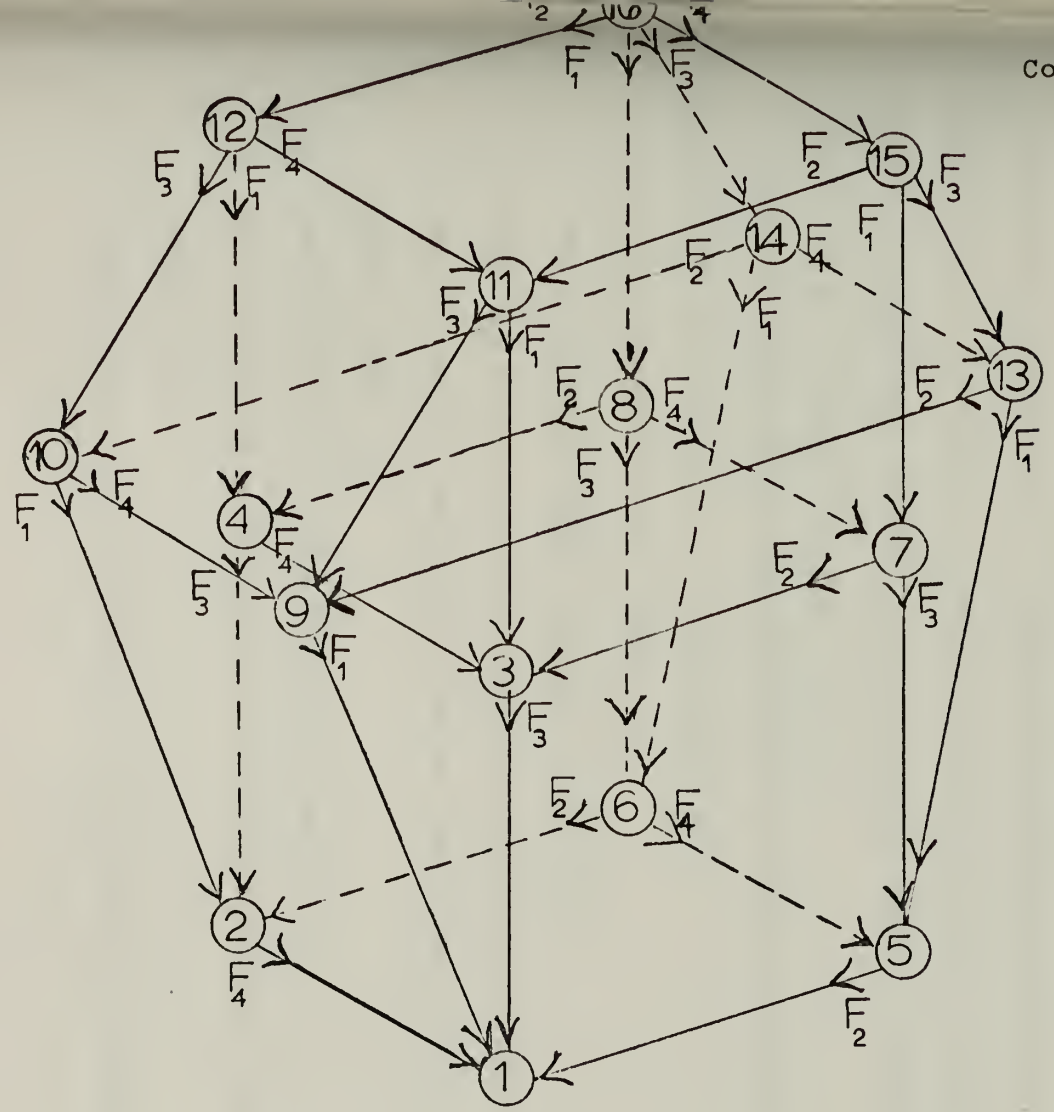


Figure C .1 FOUR CLEARANCE SYSTEM CONFIGURATIONS



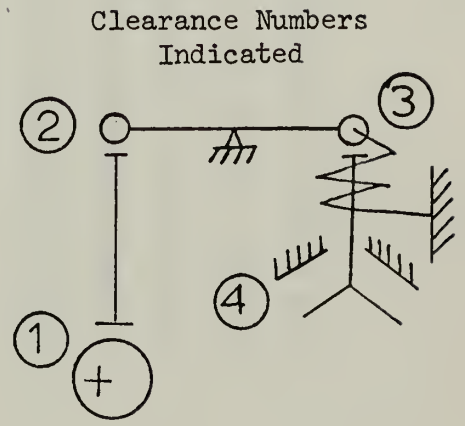


Figure C.2 4 Clearance Configuration Flow Diagram

APPENDIX D

COMPUTER CONTROL CARDS

A. IBM-360 COMPUTER CONTROL CARDS

As previously noted subroutines were complied and placed on a 2314 Disk Storage Device. This accomplished two goals. First, it eliminated the requirement to physically read into the computer a large number of punched cards. Second, it significantly reduced program execution time by greatly reducing the FORT step. This allowed the program to execute in a higher job class.

The following figures list the control cards required to accomplish various disk manipulations. A complete explaination will not be attempted here, but merely a listing of procedures that have been found to be effective. Section 3.4 of the Users Manual, reference (13), should be reviewed for more information.

In the following example control cards, the data set name is S0274. NILKA and is placed on public disk Mary.

1. Initialize disk space, Figure D.1.
2. Load subroutine NEWMRK onto disk, Figure D.2.
3. List disk data set members and space remaining, Figure D.3.
4. Execute program reading only control cards, main, and data cards, Figure D.4.
5. Load main program, CWG, onto disk, Figure D.5.
6. Execute program reading only control cards and data cards, Figure D.6.
7. Compress disk area when available space has been exceeded.

a. Read disk members onto scratch disk without intermediate spacing, Figure D.7.

b. Copy all members to users disk, Figure D.8.

c. Copy all members except NEWMRK to users disk, Figure D.9.

```
//    JOB CARD  (GREEN CARD)
// EXEC  FORTHCL,PARM.LINK='NCAL,LET'
//FORT.SYSIN DD *
--- SUBROUTINE NEWMRK CARDS ---
        STEP DELIMINATOR /* CARD
//LINK.SYSLMOD DD UNIT=2314,VOL=SER=MARY,DSN=S0274.NILKA,
//     DISP=(NEW,KEEP),SPACE=(CYL,(6,1,6)),LABEL=EXPDT=71365
//LINK.SYSIN DD *
   NAME    NEWMRK(R)
  END OF JOB /*           ( ORANGE CARD )
```

Figure D.1 Initalize Disk Space

```
//    JOB CARD  (GREEN CARD)
// EXEC  FORTHCL,PARM.LINK='NCAL,LET'
//FORT.SYSIN DD *
--- SUBROUTINE NEWMRK CARDS ---
        STEP DELIMINATOR /* CARD
//LINK.SYSLMOD DD UNIT=2314,VOL=SER=MARY,DSN=S0274.NILKA,
//     DISP=OLD,SPACE=(CYL,(6,1,6))
//LINK.SYSIN DD *
   NAME    NEWMRK(R)
  END OF JOB /*           ( ORANGE CARD )
```

Figure D.2 Load Subroutine onto Disk

```
//    JOB CARD  (GREEN CARD)
//LIST EXEC PGM=IEHLIST,REGION=58K
//SYSPRINT DD SYSOUT=A,SPACE=(TRK,(1,1))
//DD1 DD UNIT=2314,VOL=SER=MARY,DISP=OLD
//DD2 DD UNIT=2314,VOL=SER=MARY,DISP=OLD
//SYSIN DD *,DCB=BLKSIZE=80
       LISTVTOC FORMAT,VOL=2314=MARY,DSNAME=(S0274.NILKA)
       LISTPDS DSNAME=S0274.NILKA,VOL=2314=MARY
  END OF JOB /*           ( ORANGE CARD )
```

Figure D.3 List Data Set VTOC and PDS

```
//   JOB CARD  (GREEN CARD)
// EXEC  FORTHCLG,REGION.GO=250K
//FORT.SYSIN DD *
----  MAIN PROGRAM CARDS ---
       STEP DELIMINATOR /* CARD
//LINK.PLIB  DD  DSN=S0274.NILKA,VOL=SER=MARY,DISP=SHR,UNIT=2314
//LINK.SYSIN  DD  *
   INCLUDE PLIB(BRANCH,CAM,DEBUG,DEL,DRUP,DVVS,MCK)
   INCLUDE PLIB(INITAL,MATRIX,NEWMRK,OLPLOT,SHIFT)
   INCLUDE PLIB(BKSTEP)
   INCLUDE PLIB(INPUT)
   INCLUDE PLIB(GRAPH)
   INCLUDE PLIB(AGT)
   INCLUDE PLIB(THESIS)
   INCLUDE PLIB(PRINT)
   INCLUDE PLIB(ARRAY)
       STEP DELIMINATOR /* CARD
//GO.FT06F001 DD SYSOUT=A,SPACE=(CYL,(4,2))
//GO.SYSIN DD *
---  DATA CARDS ---
  END OF JOB /*           ( ORANGE CARD )
```

Figure D.4 Execute Program with Subroutines on Disk

```
//   JOB CARD  (GREEN CARD)
//  EXEC  FORTHCL,PARM.FORT='NAME=CWG,LOAD,MAP',
//        PARM.LINK='LET,NCAL,MAP,XREF'
//FORT.SYSIN DD *
---  MAIN PROGRAM CARDS ---
       STEP DELIMINATOR /* CARD
//LINK.SYSLMOD DD UNIT=2314,VOL=SER=MARY,DSN=S0274.NILKA,
//    DISP=OLD,SPACE=(CYL,(6,1,6))
//LINK.SYSIN DD *
  NAME   CWG(R)
  END OF JOB /*           ( ORANGE CARD )
```

Figure D.5 Load Main Program onto Disk

```
//   JOB CARD  (GREEN CARD)
//  EXEC LGOP,REGION.GO=250K
//LINK.PLIB DD UNIT=2314,VOL=SER=MARY,DSN=S0274,NILKA,DISP=SHR
//LINK.SYSIN  DD  *
   INCLUDE PLIB(ARRAY,BKSTEP,BRANCH,CAM,DEBUG,DEL,DRUP,DVVS,GRAPH,MCK)
   INCLUDE PLIB(INITAL,INPUT,MATRIX,NEWMRK,OLPLOT,PRINT,SHIFT,THESIS)
   INCLUDE PLIB(CWG)
    ENTRY CWG
       STEP DELIMINATOR /* CARD
//GO.SYSIN  DD  *
---  DATA CARDS ---
  END OF JOB /*           ( ORANGE CARD )
```

Figure D.6 Execute Entire Program from Disk

```
//   JOB CARD  (GREEN CARD)
//STEP1  EXEC  PGM=IEHLIST
//SYSPRINT DD SYSOUT=A
//D5 DD UNIT=2314,VOL=(PRIVATE,,SER=MARY),DISP=SHR
//SYSIN    DD  *
       LISTVTOC   VOL=2314=MARY
//STEP2  EXEC  PGM=IEHPROGM
//SYSPRINT DD  SYSOUT=A
//SPOOL3   DD  DISP=OLD,UNIT=2314,VOLUME=SER=SPOOL3
//TMPLIB   DD  DISP=(NEW,KEEP),UNIT=2314,DSNAME=NILKA.TMPLIB,
//             SPACE=(CYL,(6,0,17)),DCB=(RECFM=U,BLKSIZE=7294),
//             VOLUME=SER=SPOOL3
//SYSIN    DD  *
  SCRATCH  DSNAME=S0274.NILKA,VOL=2314=SPOOL3,PURGE
  RENAME   DSNAME=NILKA.TMPLIB,VOL=2314=SPOOL3,NEWNAME=S0274.NILKA
       STEP DELIMINATOR /* CARD
//STEP3  EXEC  PGM=IEBCOPY
//SYSPRINT DD  SYSOUT=A
//SYSUT1   DD  DISP=OLD,UNIT=2314,DSNAME=S0274.NILKA,VOLUME=SER=MARY
//SYSUT2   DD  DISP=OLD,UNIT=2314,DSNAME=S0274.NILKA,VOLUME=SER=SPOOL3
//SYSIN    DD  *
  COPY
  END OF JOB /*          ( ORANGE CARD )
```

Figure D.7 Read Data Set Members onto Scratch Disk

```
//   JOB CARD  (GREEN CARD)
//STEP3  EXEC  PGM=IEHPROGM
//SYSPRINT DD  SYSOUT=A
//MARY     DD  DISP=OLD,UNIT=2314,VOLUME=SER=MARY
//SYSIN    DD  *
  SCRATCH  DSNAME=S0274.NILKA,VOL=2314=MARY,PURGE
       STEP DELIMINATOR /* CARD
//STEP4  EXEC  PGM=IEBCOPY
//SYSPRINT DD  SYSOUT=A
//SYSUT1   DD  DISP=OLD,UNIT=2314,DSNAME=S0274.NILKA,VOLUME=SER=SPOOL3
//SYSUT2   DD  DISP=(NEW,KEEP),UNIT=2314,DSNAME=S0274.NILKA,
//             SPACE=(CYL,(6,1,6)),DCB=(RECFM=U,BLKSIZE=7294),
//             VOLUME=SER=MARY,LABEL=EXPDT=71365
//SYSIN    DD  *
  COPY
  END OF JOB /*          ( ORANGE CARD )
```

Figure D.8 Copy all Data Set Members

```
//   JOB CARD  (GREEN CARD)
//STEP3  EXEC  PGM=IEHPROGM
//SYSPRINT DD  SYSOUT=A
//MARY     DD  DISP=OLD,UNIT=2314,VOLUME=SER=MARY
//SYSIN    DD  *
  SCRATCH  DSNAME=S0274.NILKA,VOL=2314=MARY,PURGE
       STEP DELIMINATOR /* CARD
//STEP4  EXEC  PGM=IEBCOPY
//SYSPRINT DD  SYSOUT=A
//SYSUT1   DD  DISP=OLD,UNIT=2314,DSNAME=S0274.NILKA,VOLUME=SER=SPOOL3
//SYSUT2   DD  DISP=(NEW,KEEP),UNIT=2314,DSNAME=S0274.NILKA,
//             SPACE=(CYL,(6,1,6)),DCB=(RECFM=U,BLKSIZE=7294),
//             VOLUME=SER=MARY,LABEL=EXPDT=71365
//SYSIN    DD  *
  COPY   TYPCOPY=E,MAXNAME=1
  MEMBER NAME=(NEWMRK)
  END OF JOB /*          ( ORANGE CARD )
```

Figure D.9 Copy Part of Data Set Members

B. SDS-9300 COMPUTER CONTROL CARDS

Transferring the SDS-9300 program, in Fortran source code, from punched cards to magnetic tape is a relatively easy task. Once accomplished, repeated compiling and execution of the program is made much easier. Figure D.10 indicates the control cards required to read the punched cards onto magnetic tape.

```
 SDS-9300 COMPUTER BINARY BOOT CARD*
¬JOB
¬LOAD X, TAPEDT
$
+
--- MAIN PROGRAM CARDS ---
=EOF
--- SUBROUTINE BAR1 CARDS ---
--- SUBROUTINE BAR2 CARDS ---
--- SUBROUTINE BAR3 CARDS ---
--- SUBROUTINE BAR4 CARDS ---
=EOF
--- SUBROUTINE CAM CARDS ---
=EOF
 ETC.  UNTIL ALL SUBROUTINES ARE READ.
=EOF
```

*Indicates card supplied by Computer Laboratory

Figure D.10 Transferring FORTRAN Source Code From Cards to Magnetic Tape

The computer laboratory provided routine TAPEDT enables the user to change the program coding with a minimum of cards, while the program remains on the tape.

Figure D.11 shows the required control cards to compile, load, and execute the magnetic tape Fortran source program.

```
 SDS-9300 COMPUTER BINARY BOOT CARD*
¬JOB
$
¬ASSIGN SI=MT2A
¬REWIND SI
¬DATE 17,DEC,1971
¬TITLE .              CHARLES  W.  GNILKA - -  THESIS - -
¬AGT
¬ASSIGN 4=MT4A
¬LABEL MAIN
¬FORTRAN GO
¬LABEL CAM
¬FORTRAN GO
¬LABEL MIDBAR
¬FORTRAN GO
¬LABEL SPRCTR
¬FORTRAN GO
¬LABEL BAR
¬FORTRAN GO
¬LABEL DISPLY
¬FORTRAN GO
¬LABEL INITAL
¬FORTRAN GO
¬LABEL READ
¬FORTRAN GO
¬LOAD XR,MAP
¬SEG MAIN-BAR-CAM-(MIDBAR,SPRCTR,DISPLY,INITAL,READ)
¬DATA
```

*Indicates Card Supplied by Computer Laboratory

Figure D.11 Program Execution From FORTRAN Object on Magnetic Tape

To place the program on magnetic tape as binary executable code, the control cards are as in Figure D.11 with an additional control card immediately after the Δ JOB card. Figure D.12 indicates the required control cards.

```
 SDS-9300 COMPUTER BINARY BOOT CARD*
¬JOB
$
¬ASSIGN GO=MT3A
   ( THE REMAINING CONTROL CARDS ARE EXACTLY AS GIVEN ABOVE )
```

Figure D.12 Placing Program as Binary Code on Magnetic Tape

Once the binary code is on magnetic it may be executed approximately 75% faster than in uncompiled FORTRAN source form. The control cards to accomplish this are shown in Figure D.13

```
 SDS-9300 COMPUTER BINARY BOOT CARD*
¬JOB
$
¬AGT
¬ASSIGN BI=MT3A
¬ASSIGN GO=BI
¬ASSIGN SI=MT3A
¬LOAD XR,MAP
¬SEG MAIN-BAR-CAM-(MIDBAR,SPRCTR,DISPLY,INITAL,READ)
¬DATA
```

Figure D.13 Program Execution From Binary Code on Magnetic Tape

APPENDIX E

IBM-360 COMPUTER PROGRAM DATA CARDS

```
      GNILKA, C. W. 17 DECEMBER   THREE CLEARANCES  NO. 1
1,000 RPM     VALVE SEAT
1000.             RPM
.7          NO     CLEARANCE AT VALVE SEAT AND PUSHROD/ROCKER
ES              PRINT OUT MATRICS   MPRINT
0             CALCOMP GRAPHS DESIRED
0             AGT OUTPUT
0  NO         PUNCHED CARDS;  MAGNETIC TAPE
.052                DEGREES TO PRINT DEBUG OUTPUT OR STOP
0    10       PRINTED OUTPUT DESIRED;   NCOUNT
10          PRINTED OUTPUT DESIRED FOR DEBUG PURPOSES - IPRINT
10               OFFLINE PRINTER GRAPH
  1           IDEG - - FORCED TO STAY IN CONFIG 7
).000001            DELT- - TIME INCREMENT
     DISPL. DIFF. BETWEEN ROD & ROCKER ** Q(2)-Q(8)
     DISPL. DIFF. BETWEEN CAM & ROD ** Q(1)-Q(9)
     CAM PROFILE ** Q(9)
     DISPL. OF LOWER END OF PUSHROD ** Q(1)
     FORCE ON PUSHROD ** F(1)
     AXIAL OSCILLATIONS OF THE PUSHROD ** Q(8)-Q(1)
     DISPLACEMENT OF VALVE ** Q(7)
     POSITION OF VALVE SEAT ** Q(10)
     FORCE ON ROCKER ** F(2)
     AXIAL OSCILLATIONS OF THE VALVE STEM
     FORCE ON VALVE ** F(7)
     CAM PROFILE AND DISPL. OF PUSHROD
     DISPL. OF VALVE AND VALVE SEAT
DEGREES OF CAM ROTATION
```

APPENDIX F

This appendix presents two additional examples for comparison with the 11,000 RPM examples presented in chapter 6.C.

A. EXAMPLE 3, THREE CLEARANCES, 9,000 RPM, VALVE SEAT

Approximately 800 degrees of cam rotation is indicated on the associated graphs. These graphs only indicate the indicate the major system points of interest and are not otherwise annotated. The graphs, in order of presentation are:

1. Figure F.1
   a. Cam Profile, $q_9 \times 10^{-1}$
   b. Displacement of lower end of pushrod
      $q_1 \times 10^{-1}$
   c. Displacement difference between cam and pushrod
      $q_1 - q_9 \times 10^{-3}$
2. Figure F.2, Force on Pushrod
   $F_1 \times 10^{2}$
3. Figure F.3, Force on Rocker
   $F_2 \times 10^{2}$
4. Figure F.4, Force on Valve
   $F_7 \times 10^{2}$
5. Figure F.5, Displacement of Valve
   $q_7 \times 10^{-1}$
6. Figure F.6, Axial Oscillations of the Pushrod
   $(q_8 - q_1) \times 10^{-3}$
7. Figure F.7, Axial Oscillation of the Valve Stem
   $(q_7 - q_4) \times 10^{-3}$

8. Figure F.8

   a. Displacement Difference between Cam and Pushrod

      $(q_1 - q_9) \times 10^{-3}$

   b. Displacement Difference between Pushrod and Rocker

      $(q_2 - q_8) \times 10^{-2}$

B. EXAMPLE 3, THREE CLEARANCES 10,000 RPM, VALVE SEAT

This last example referred to in chapter 6.C. also presents approximately 800 degrees of cam rotation. These graphs only indicate the major system points of interest and are not otherwise annotated. The graphs, in order of presentation are:

1. Figure F.9

   a. Cam Profile, $q_9 \times 10^{-1}$

   b. Displacement of lower end of pushrod

      $q_1 \times 10^{-1}$

   c. Displacement difference between cam and pushrod

      $q_1 - q_9 \times 10^{-3}$

2. Figure F.10, Force on Pushrod

   $F_1 \times 10^2$

3. Figure F.11, Force on Rocker

   $F_2 \times 10^2$

4. Figure F.12, Force on Valve

   $F_7 \times 10^2$

5. Figure F.13, Displacement of Valve

   $q_7 \times 10^{-1}$

6. Figure F.14, Axial Oscillations of the Pushrod

   $(q_8 - q_1) \times 10^{-3}$

7. Figure F.15, Axial Oscillation of the Valve Stem

   $(q_7 - q_4) \times 10^{-3}$

8. Figure F.16

a. Displacement Difference between cam and pushrod

$(q_1 - q_9) \times 10^{-3}$

b. Displacement Difference between Pushrod and Rocker

$(q_2 - q_8) \times 10^{-2}$

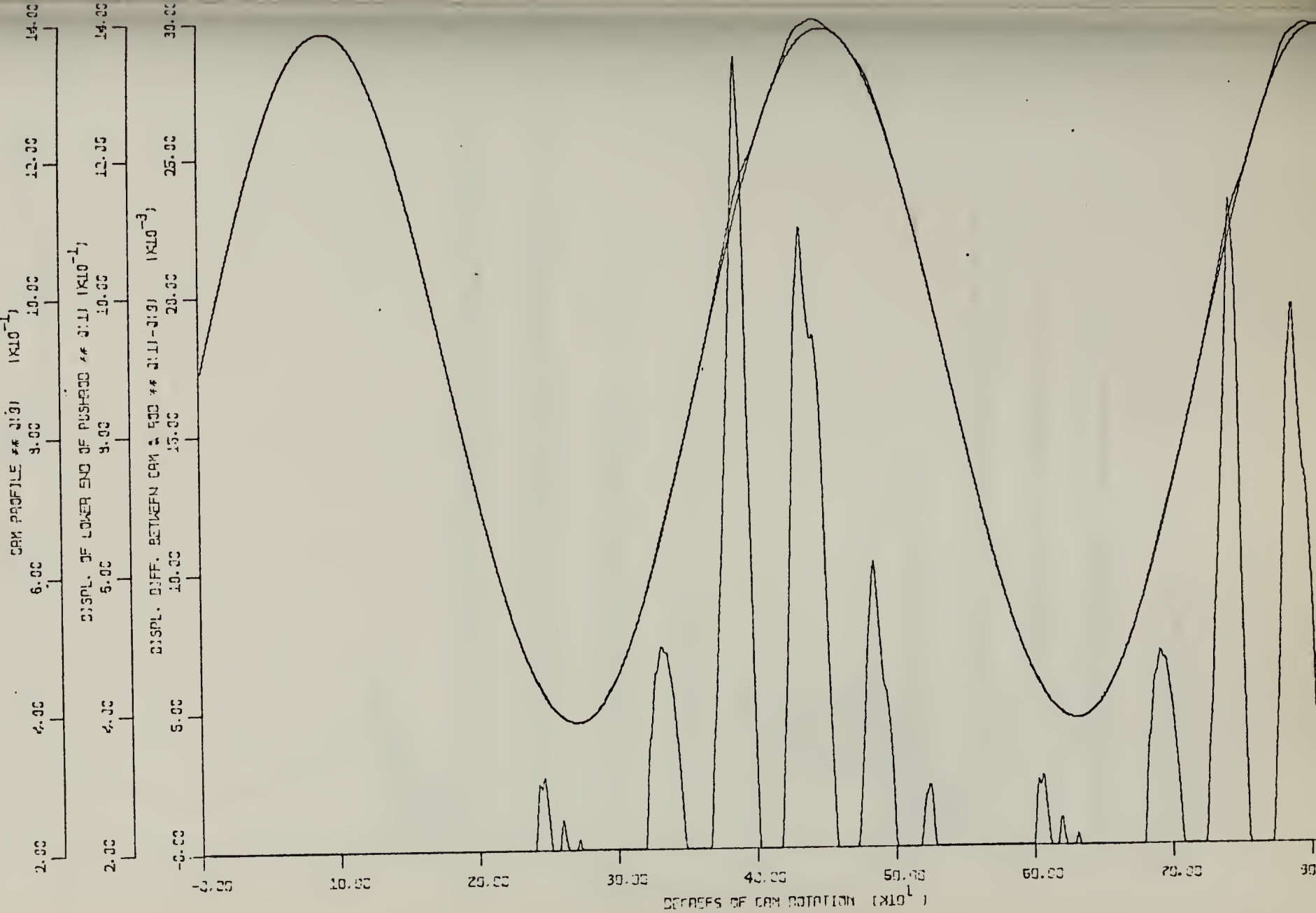


Figure F.1 THREE CLEARANCES 9,000 RPM VALVE SEAT

Figure F.2 THREE CLEARANCES 9,000 RPM

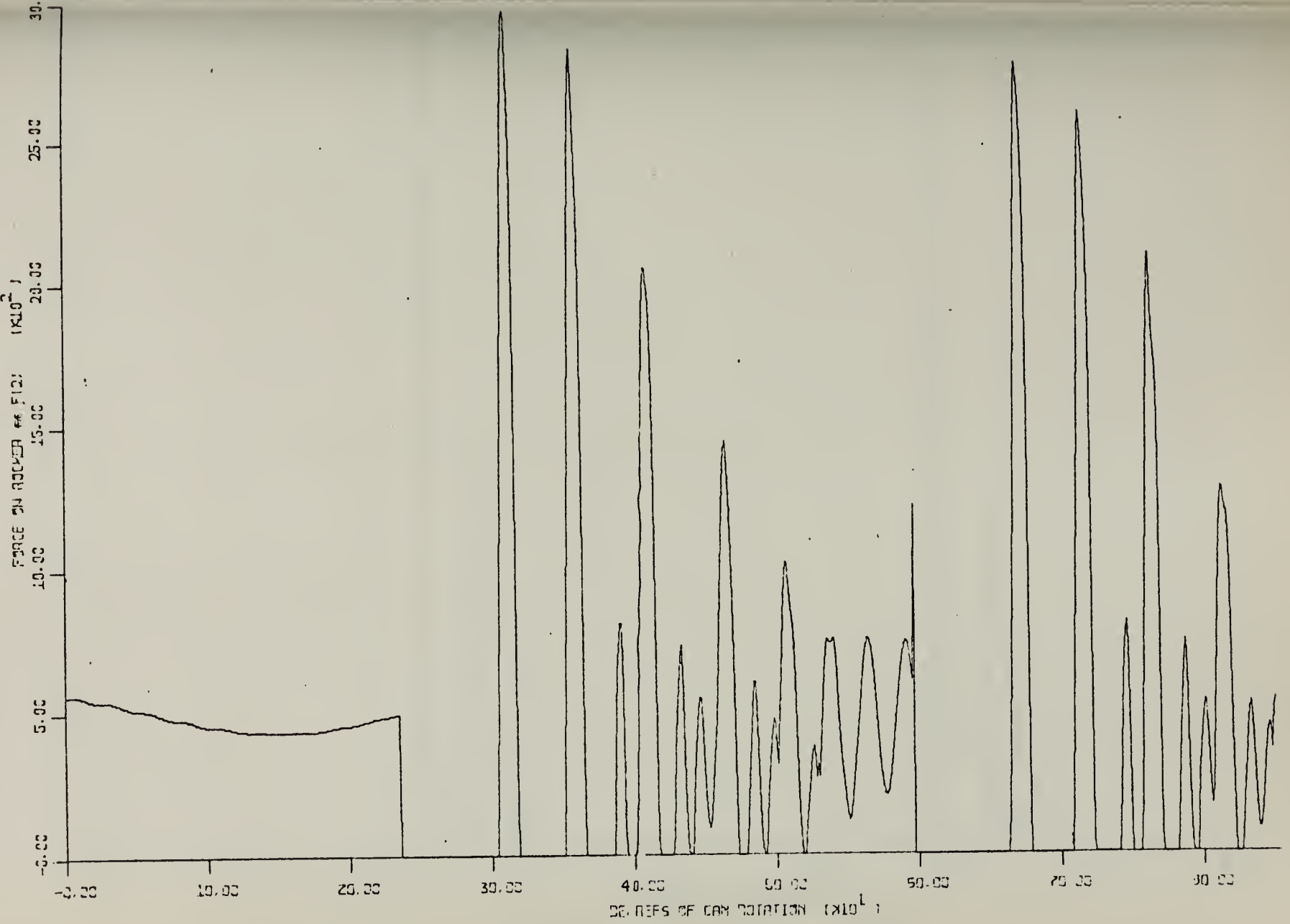
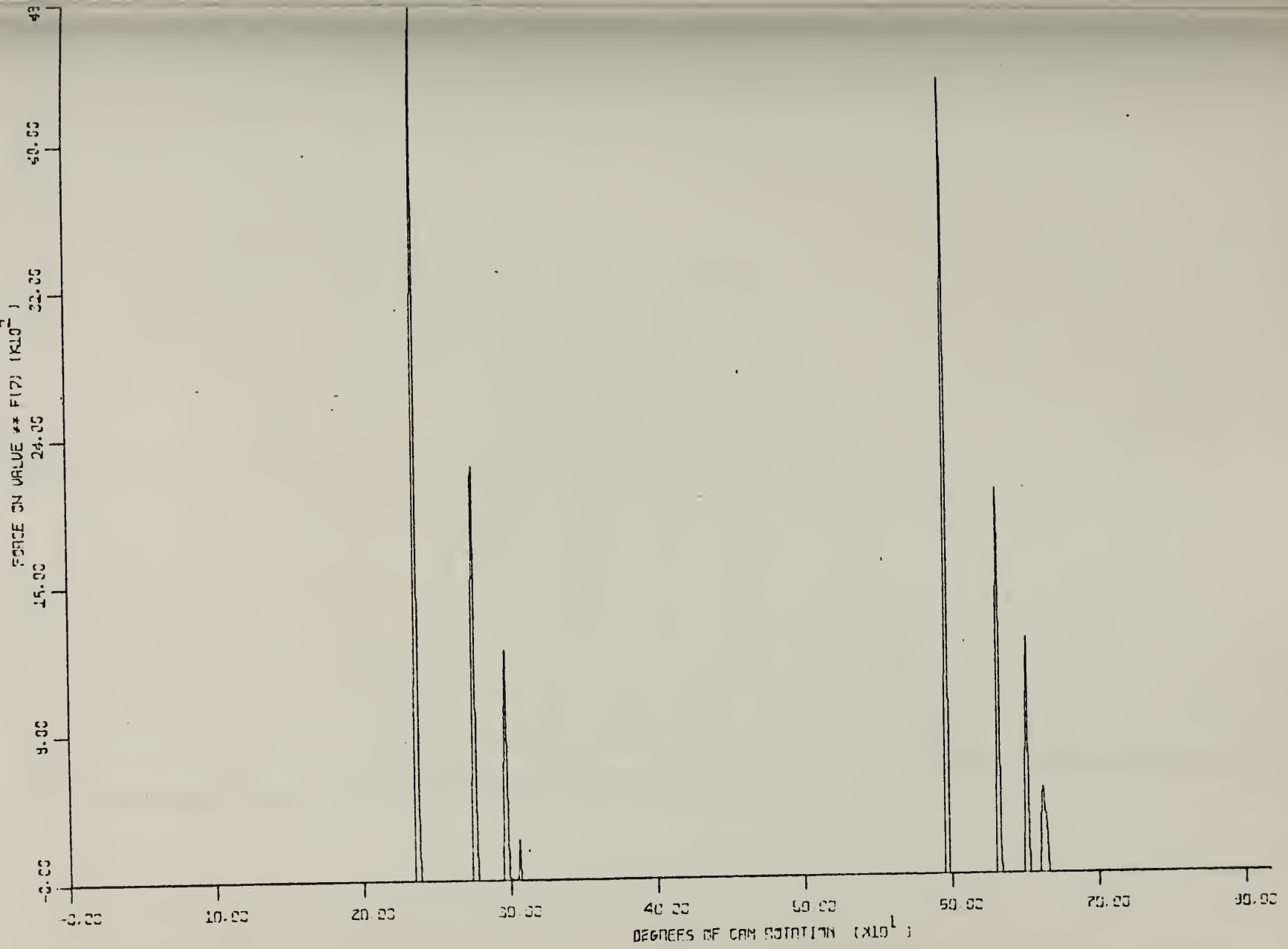


Figure F.3 THREE CLEARANCES 9,000 RPM VALVE SEAT



9,000 RPM VALVE SEAT

Figure F.4 THREE CLEARANCES

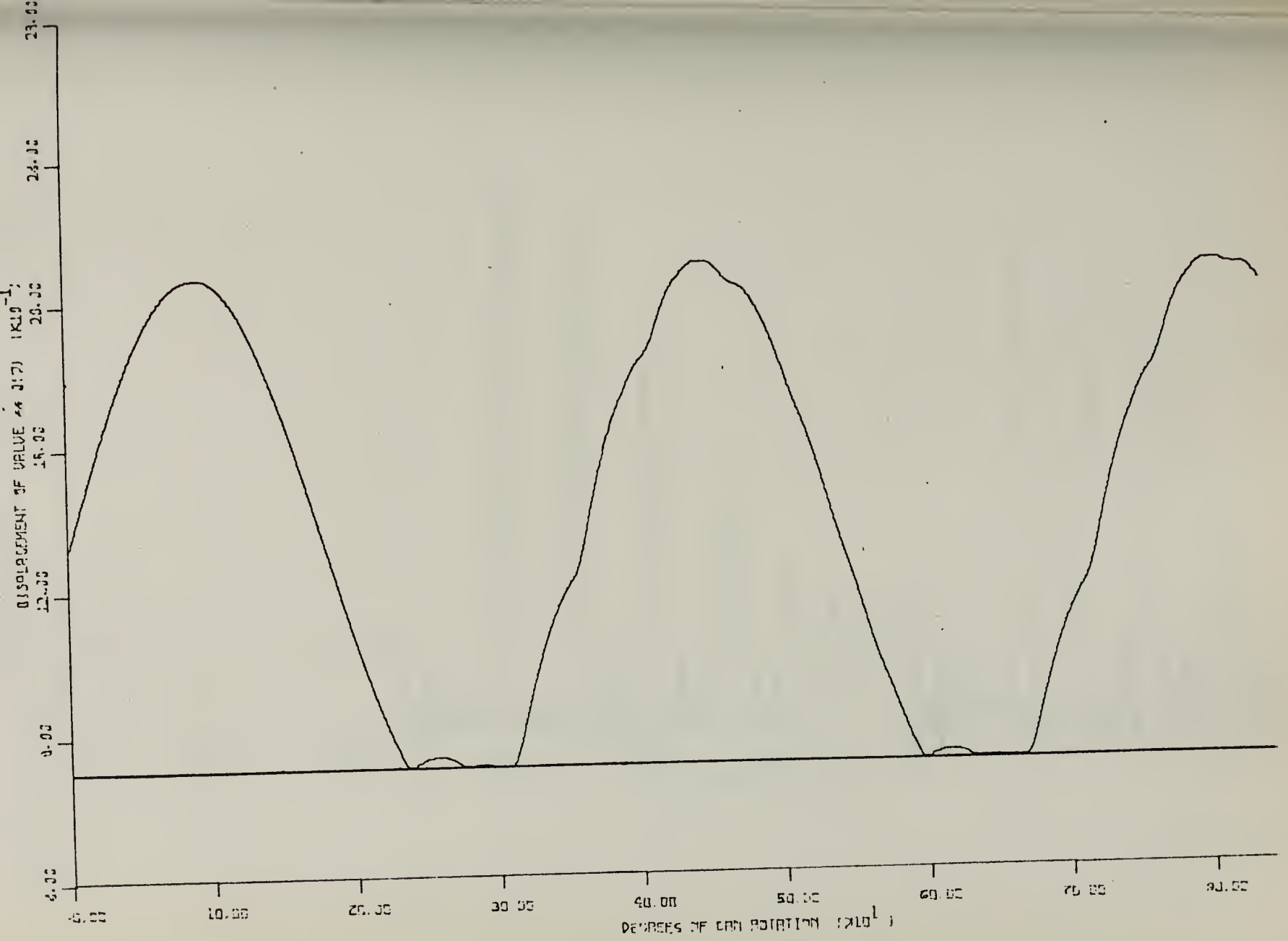


Figure F.5 THREE CLEARANCES 9,000 RPM VALVE SEAT

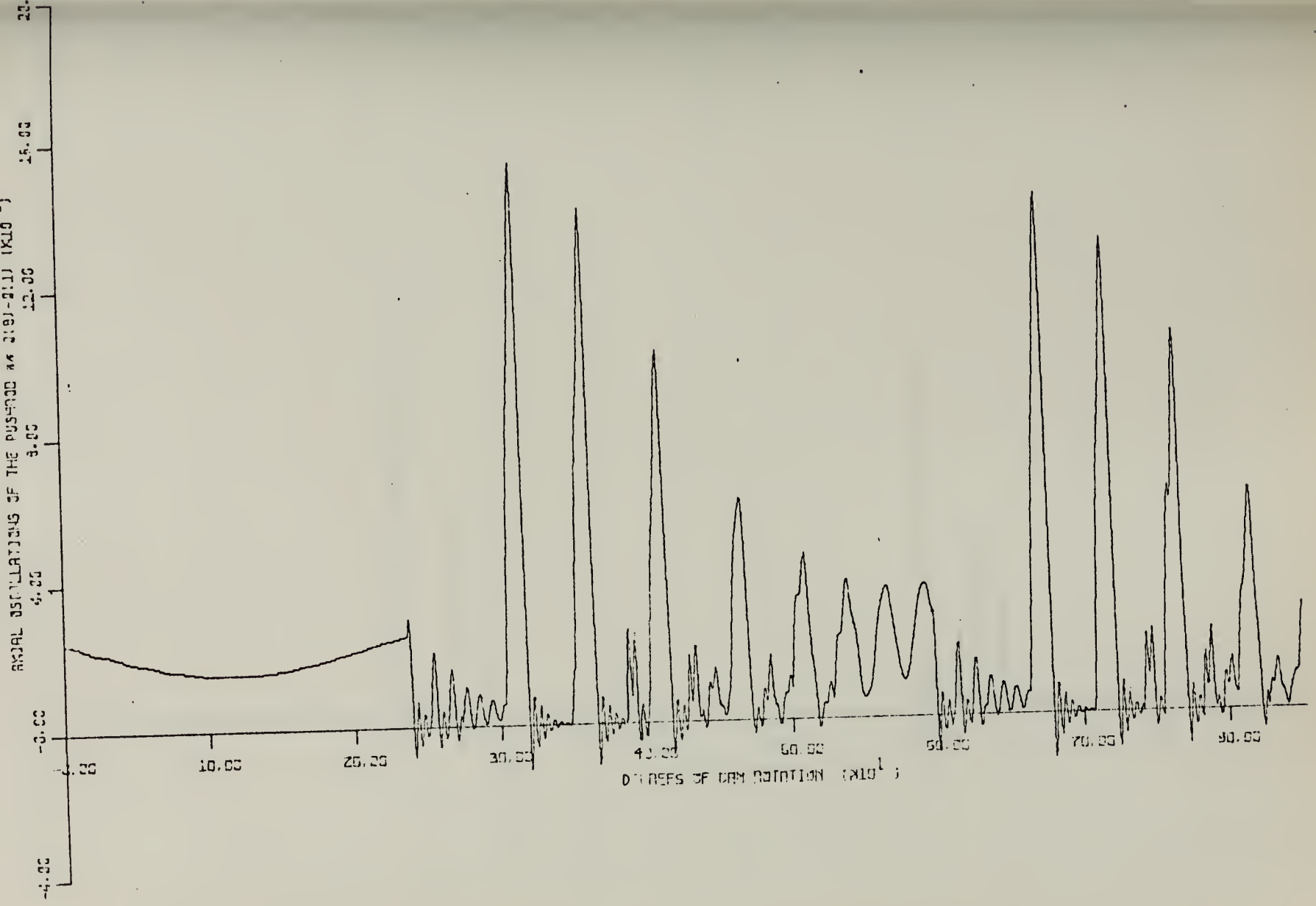


Figure F.6 THREE CLEARANCES 9,000 RPM VALVE SEAT

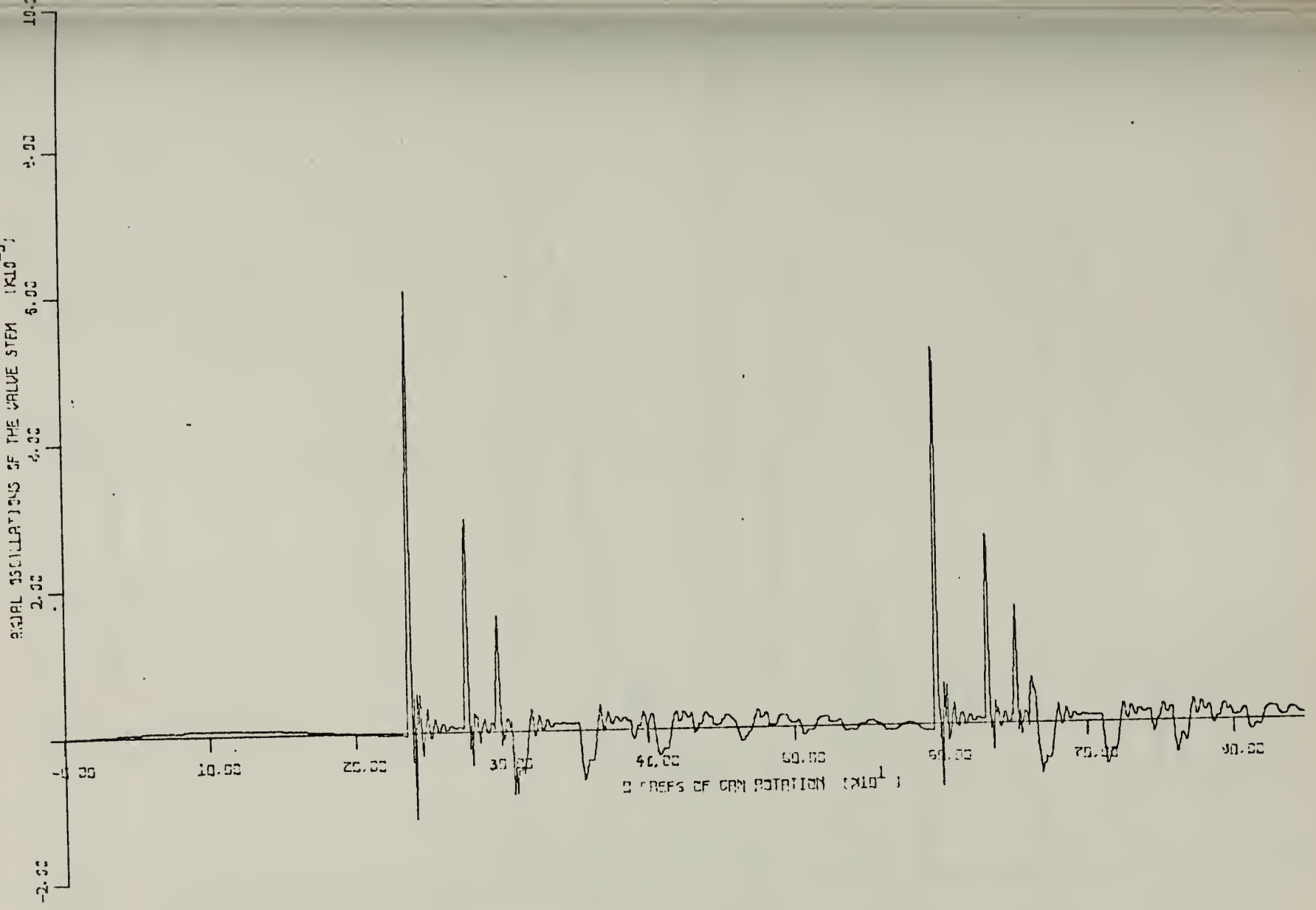


Figure F.7 THREE CLEARANCES 9,000 RPM VALVE SEAT

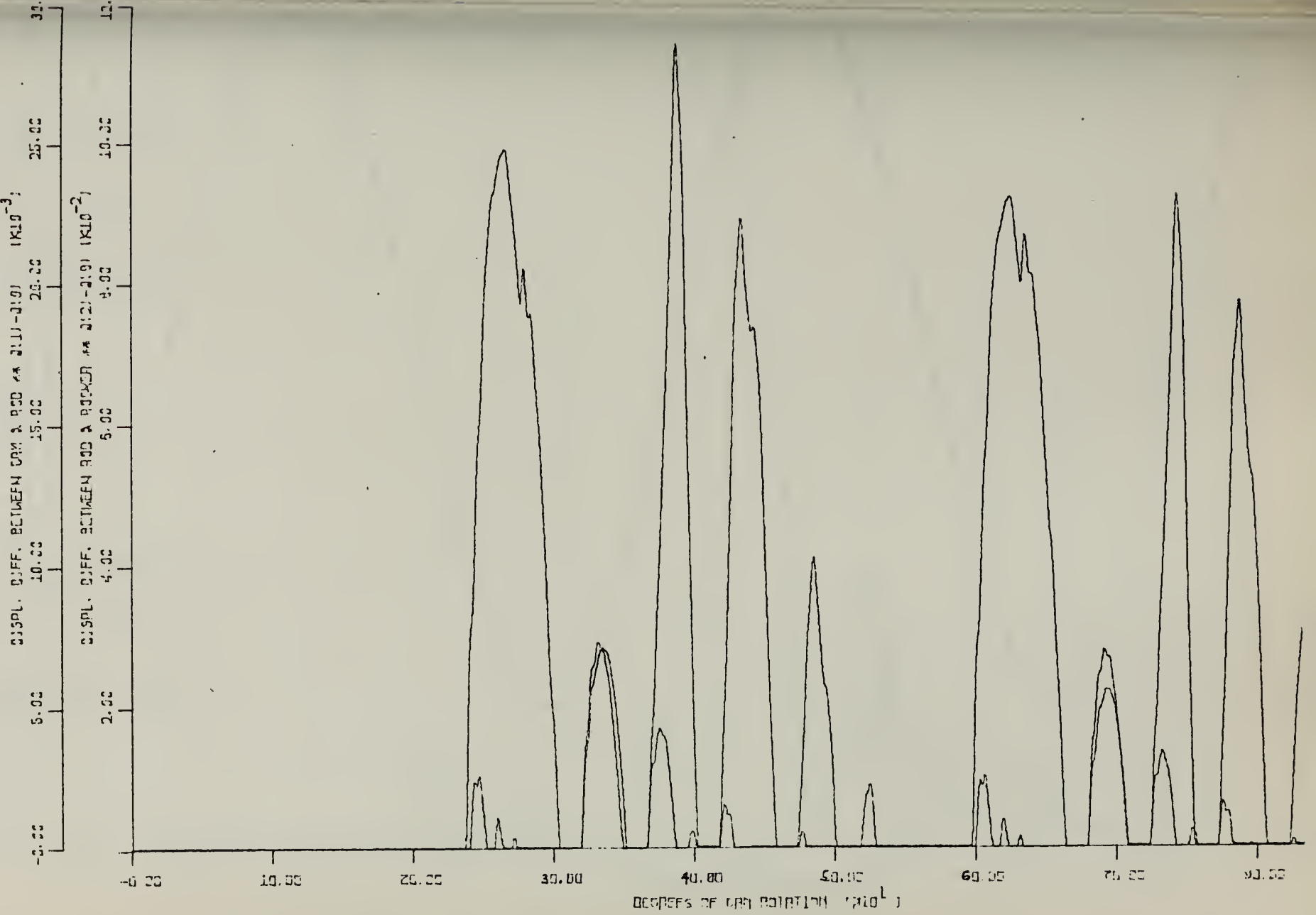


Figure F.8 THREE CLEARANCES 9,000 RPM VALVE SEAT

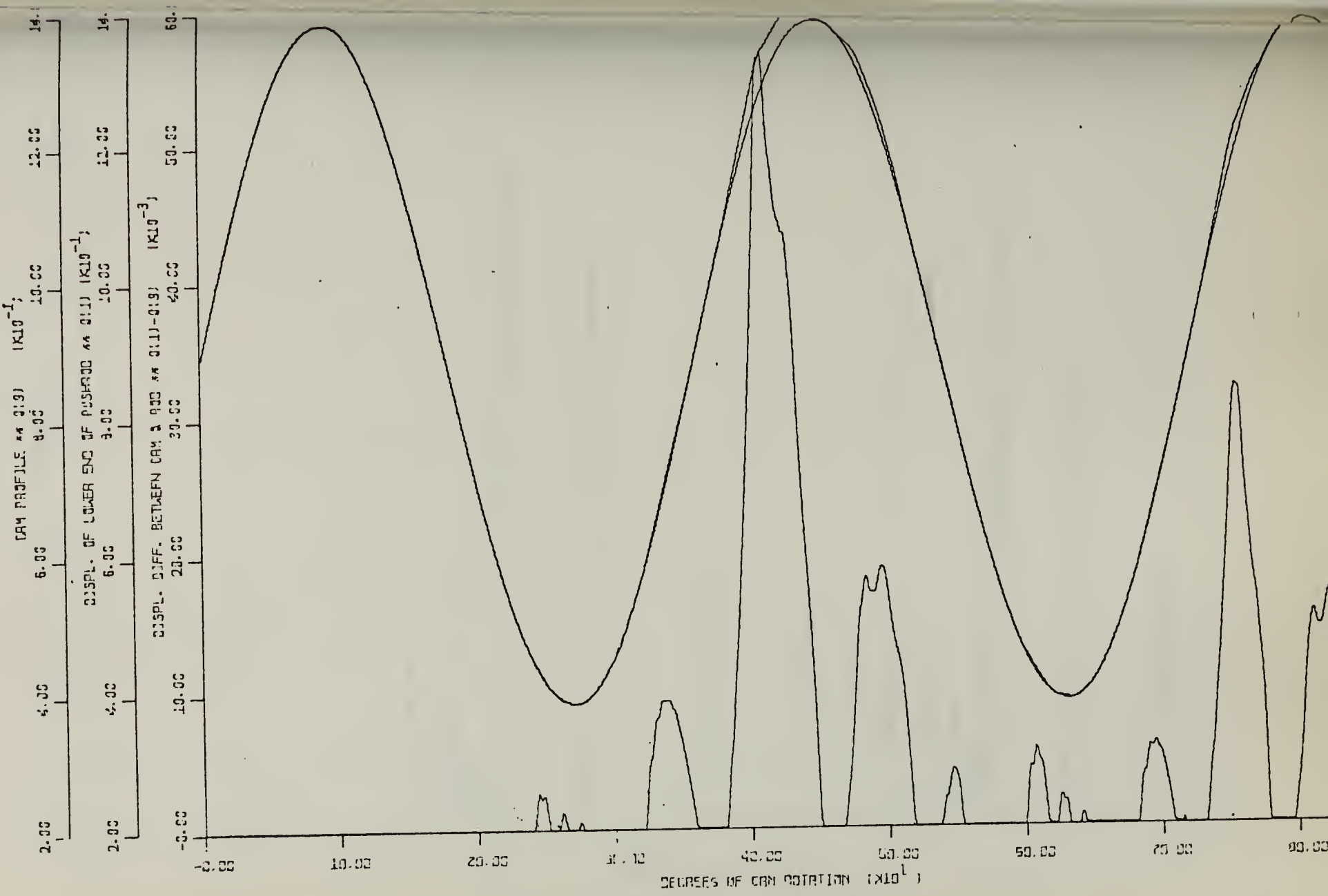

CAM PROFILE AT 0131 (X10^{-1})
DISPL. OF LOWER END OF PUSHROD AT 0111 (X10^{-1})
DISPL. DIFF. BETWEEN CAM & ROD AT 0111-0131 (X10^{-3})
DEGREES OF CAM ROTATION (X10^{1})

Figure F.9 THREE-CLEARANCES 10,000 RPM VALVE SEAT

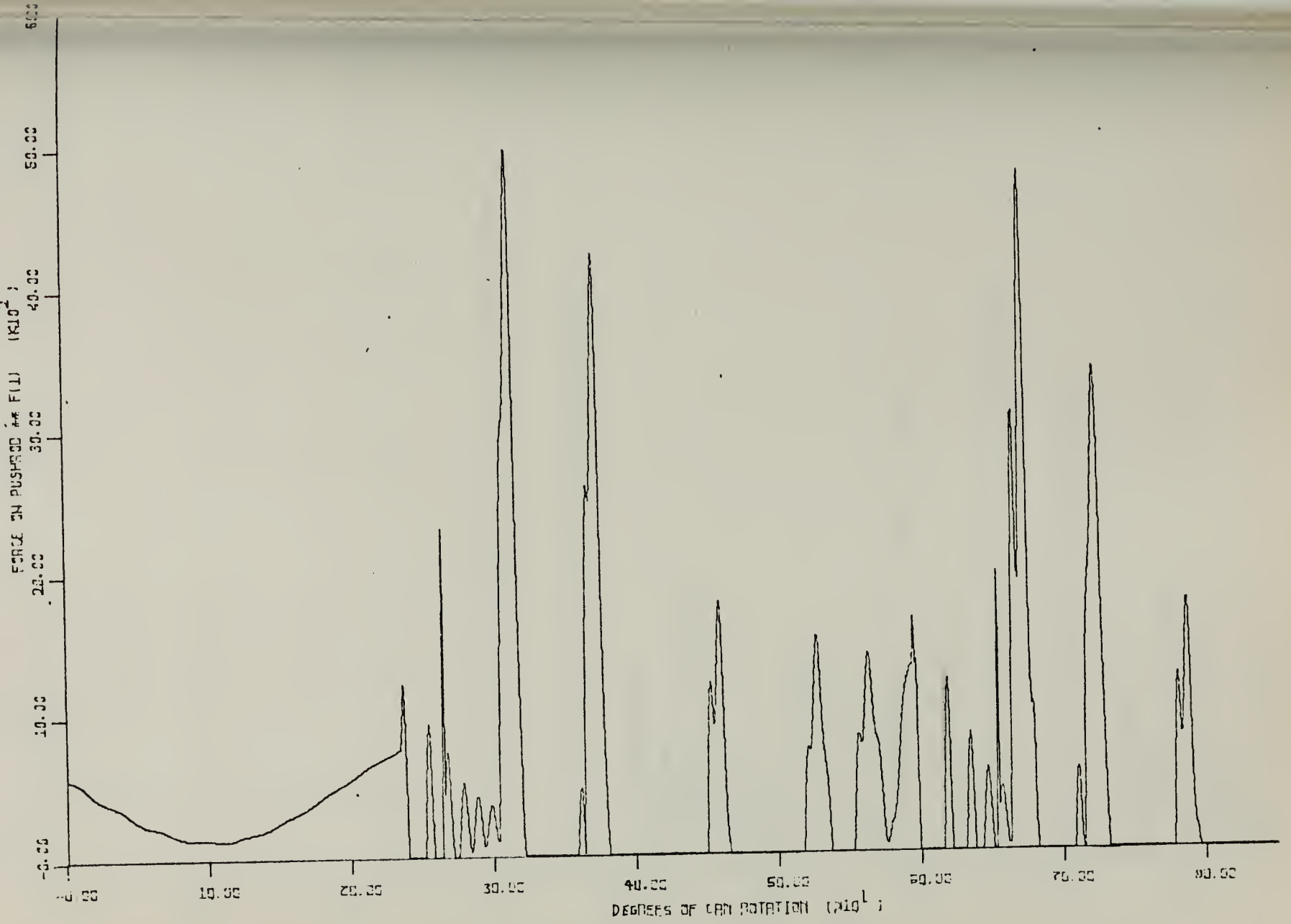


Figure F.10 THREE CLEARANCES 10,000 RPM VALVE SEAT

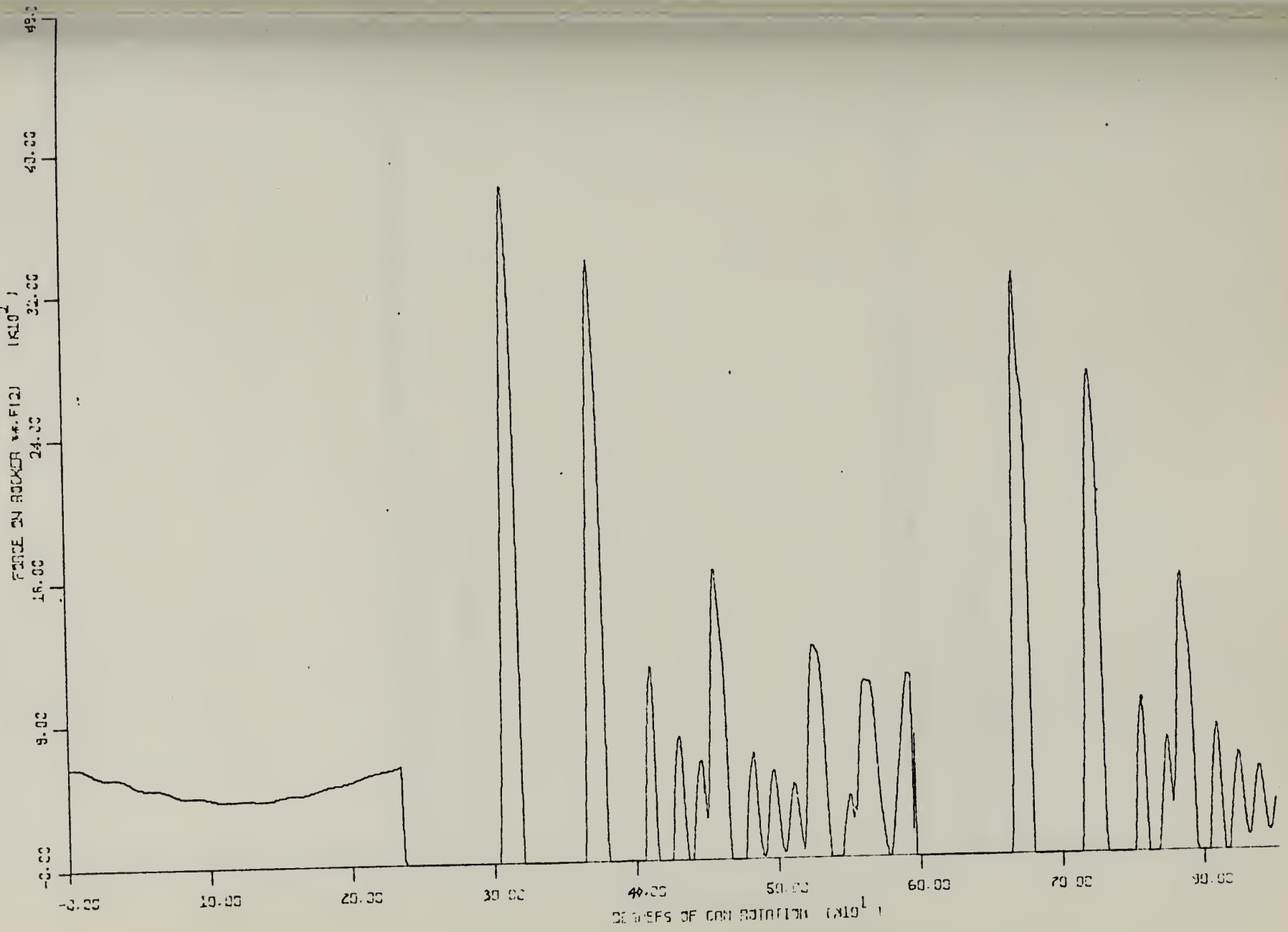


Figure F.11 THREE CLEARANCES 10,000 RPM VALVE SEAT

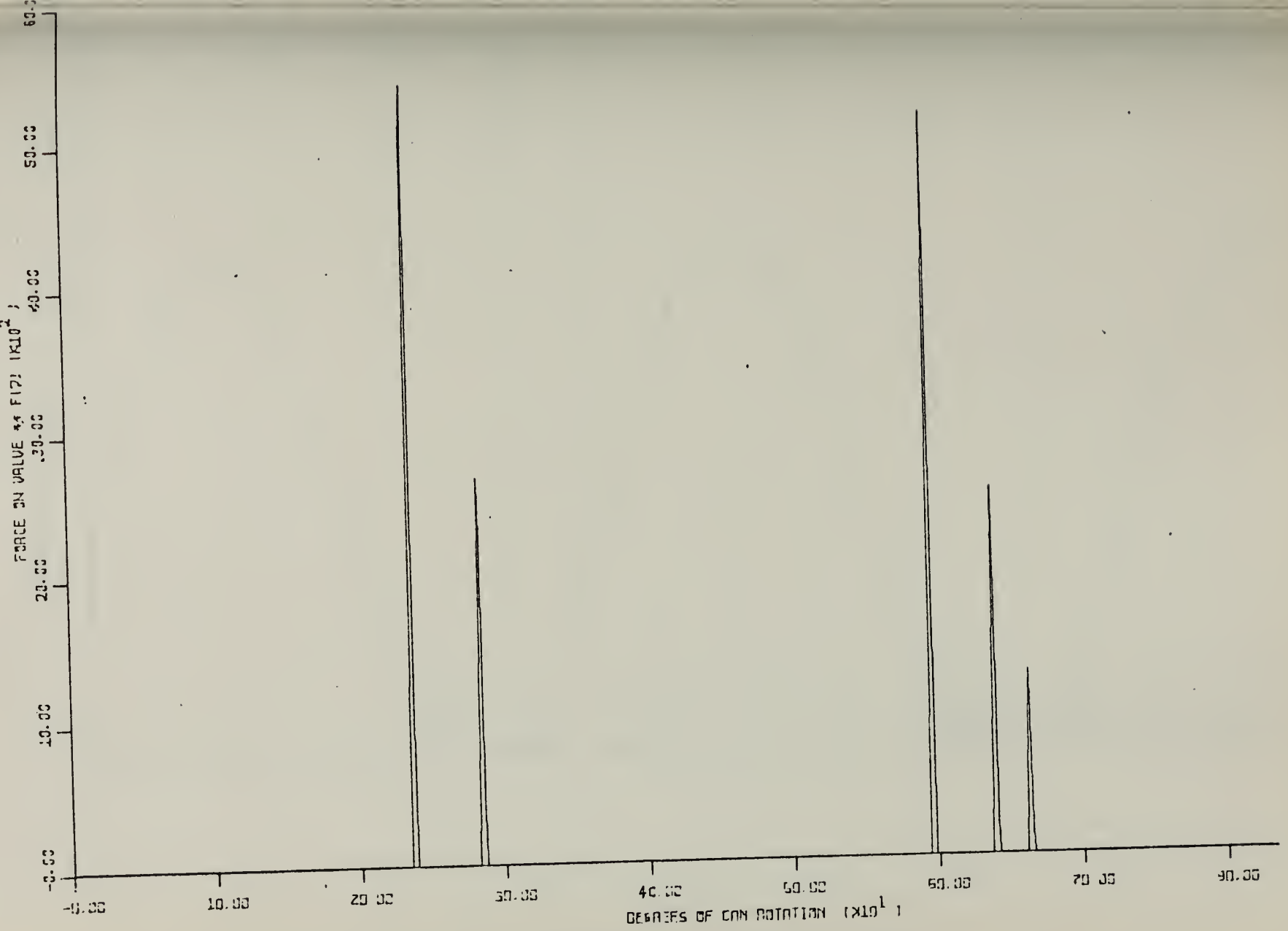


Figure F.12 THREE CLEARANCES 10,000 RPM VALVE SEAT

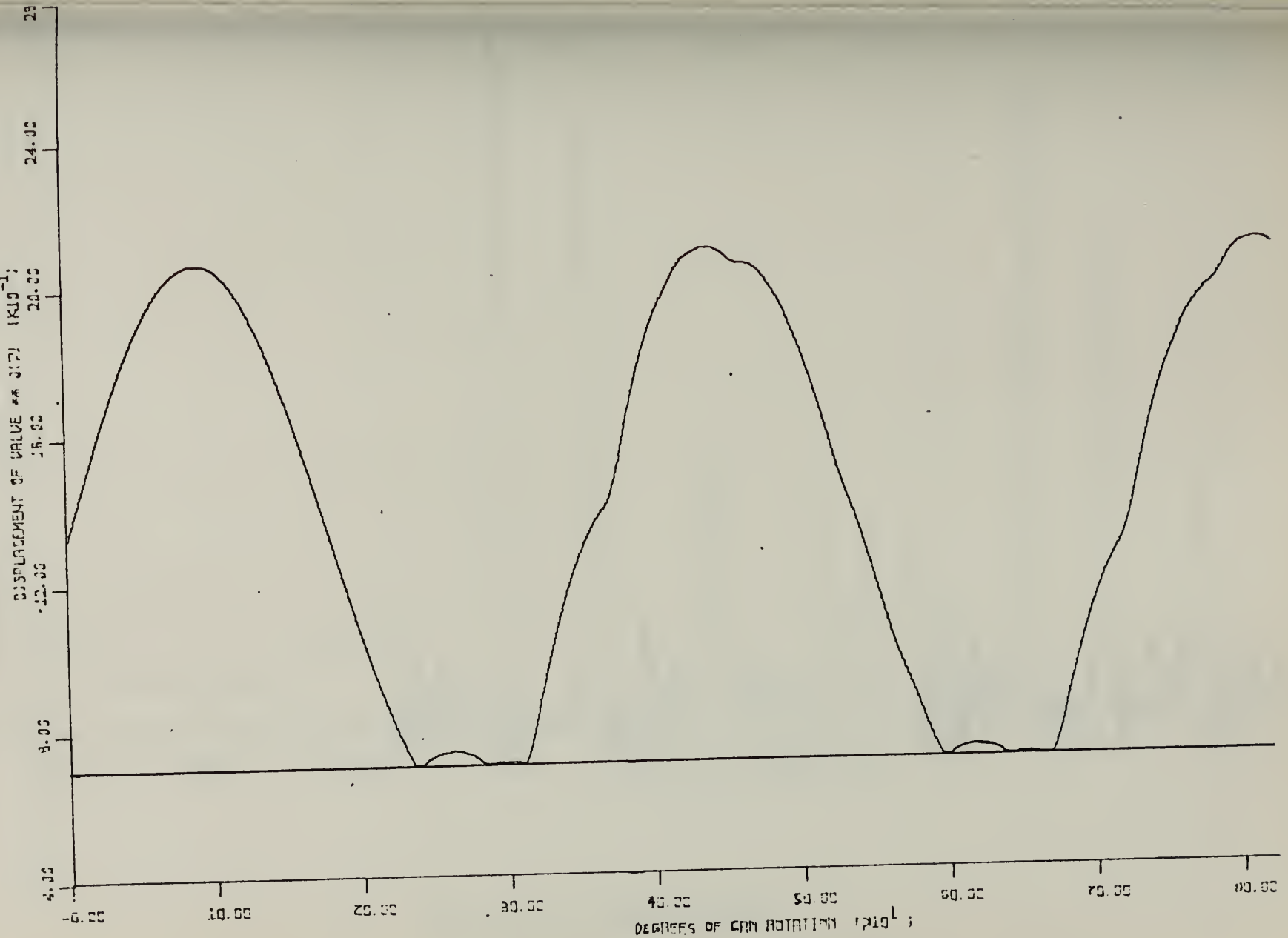


Figure F.13 THREE CLEARANCES 10,000 RPM VALVE SEAT

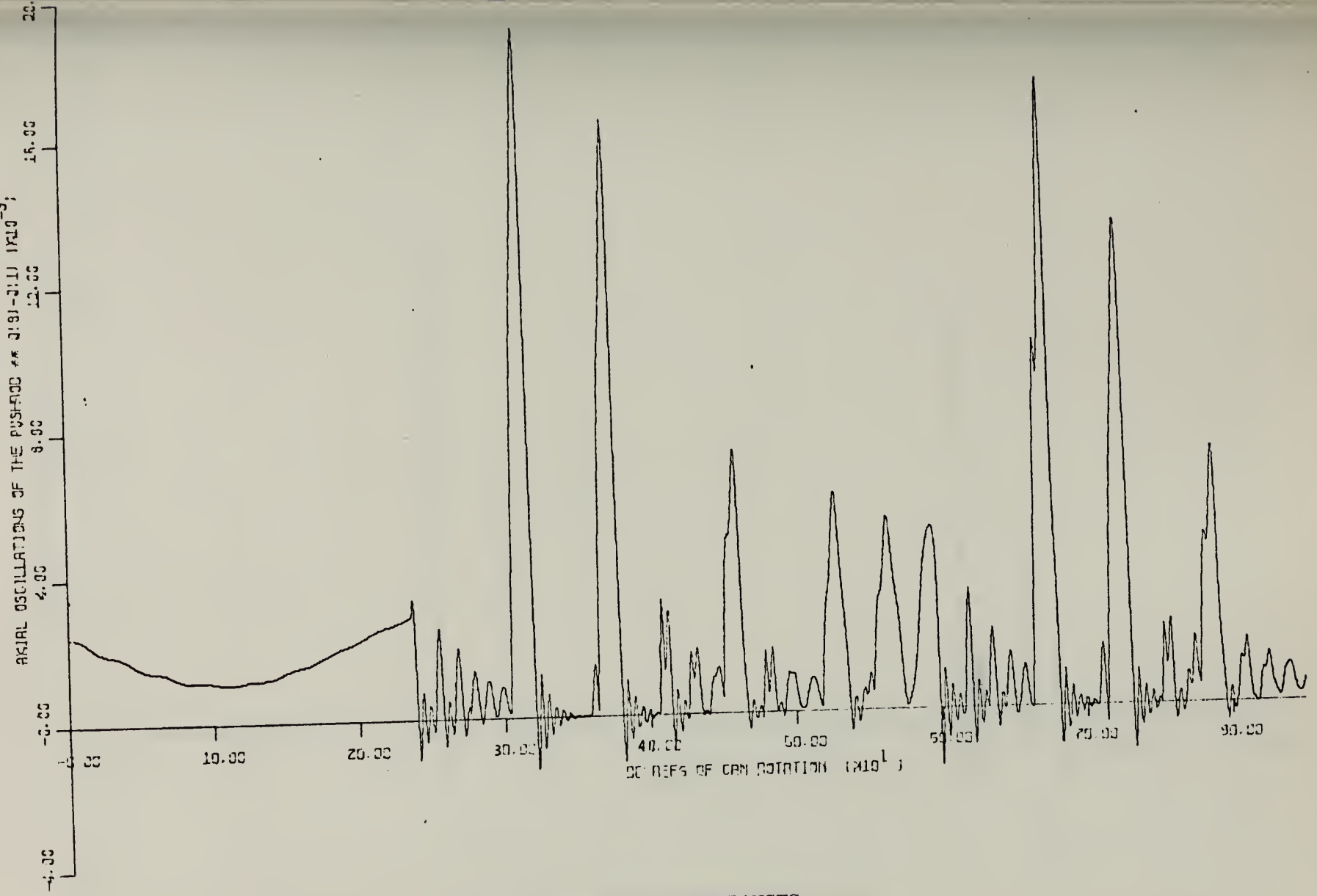


Figure F.14 THREE CLEARANCES

10,000 RPM VALVE SEAT

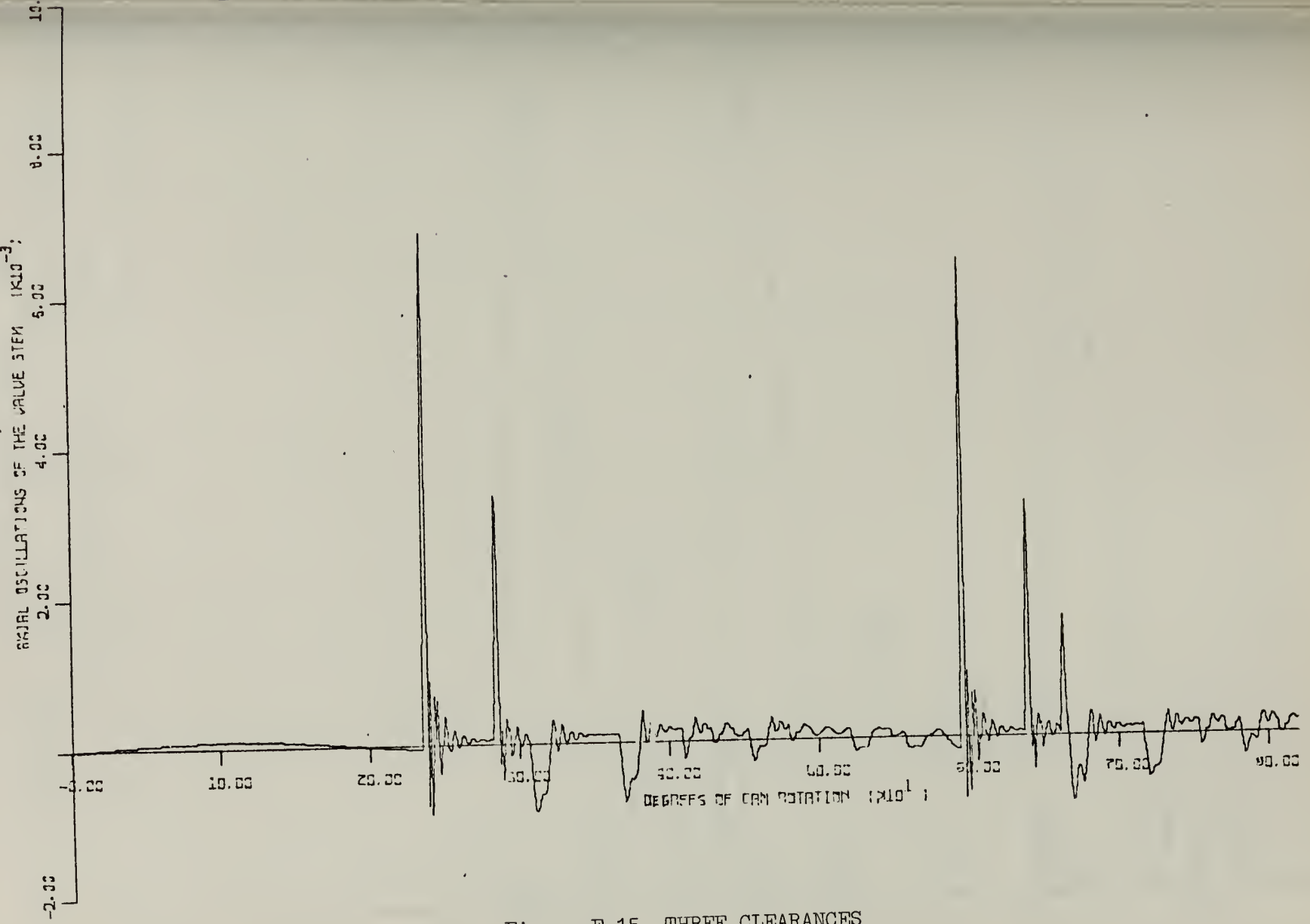


Figure F.15 THREE CLEARANCES

10,000 RPM VALVE SEAT

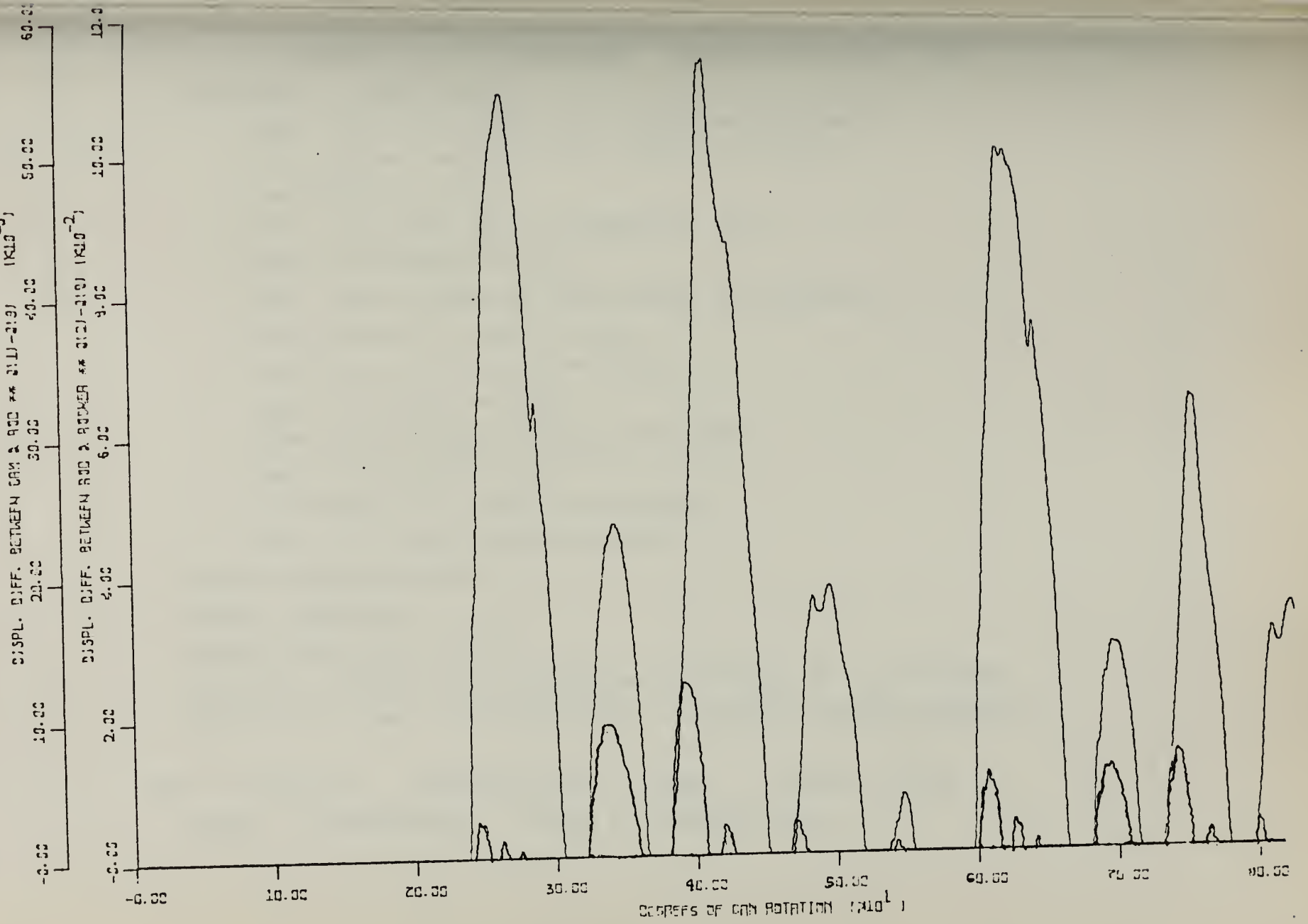


Figure F.16 THREE CLEARANCES ; 10,000 RPM VALVE SEAT

GNILKA, C. W. 17 DECEMBER THREE CLEARANCES NO. 1

11,000 RPM VALVE SEAT

DISPL. DIFF. BETWEEN ROD & ROCKER ** Q(2)-Q(8)

DISPL. DIFF. BETWEEN CAM & ROD ** Q(1)-Q(9)

CAM PROFILE ** Q(9)

DISPL. OF LOWER END OF PUSHROD ** Q(1)

FORCE ON PUSHROD ** F(1)

AXIAL OSCILLATIONS OF THE PUSHROD ** Q(8)-Q(1)

DISPLACEMENT OF VALVE ** Q(7)

POSITION OF VALVE SEAT ** Q(10)

FORCE ON ROCKER ** F(2)

AXIAL OSCILLATIONS OF THE VALVE STEM

FORCE ON VALVE ** F(7)

CAM PPOFILE AND DISPL. OF PUSHROD

DISPL. OF VALVE AND VALVE SEAT

NO AGT OUTPUT REQUESTED

DAMPING REQUESTED

CALCOMP GRAPH NOT DESIRED

VALVE SEAT IMPOSED WITH AN INITIAL CLEARANCE OF 0.70 INCHES

COORDINATES 2 AND 8 ARE NOT PINED - - THREE CLEARANCE PROBLEM

RPM = 11000.00 DAMPING COEF. = 1.000 CLEAR = 0.700

XZERO= 8.8245022D-01 FZERO = 5.0185073D 02

IBM-360 COMPUTER PROGRAM LISTING

This listing is coded in FORTRAN IV, (Refs. 10-13), to run on an IBM-360/67, with OS/360 release 18. The simulation requires 234 K bytes of core storage for 850 degrees of cam rotation, including the CALCOMP graph buffer. The offline printer array (GRID) is not included in this core storage figure. Execution time is a function of the speed of rotation of the cam. For 11,000 RPM with 850 degrees, execution time is about 4.3 minutes. The primary output parameters fill arrays for SYSOUT = B and SYSOUT = C. The B queue is for transferring data, via punched cards, for use in the SDS-9300 computer. The C queue is for plotting graphs via the CALCOMP.

```
C                                                                       00000010
C-----------------------------------------------------------------------00000020
C                                                                       00000030
C      CHARLES  W. GNILKA - - -  THESIS - - -  DECEMBER   1971          00000040
C    THE MODELING AND ANALYSIS OF AN ELASTIC MECHANISM WITH CLEARANCES  00000050
C          THREE CLEARANCES - - CAM -  VALVE SEAT  -  ROCKER            00000060
C                                                                       00000070
C-----------------------------------------------------------------------00000080
C                                                                       00000090
      INTEGER*2 GRID(  1, 1)                                            00000100
      DIMENSION FPLOT( 850,11), Y1( 850,2), Y2( 850,2), Y3(850,2),      00000110
     1          Y4(850,2), DEG(1700), DEG1(850 ), DEG2( 850,2),         00000120
     2          YNAME(20,13), YNAME1(20,2), YNAME2(20,2)                00000130
      COMMON NUNIT, IPRINT                                              00000140
      EQUIVALENCE ( FPLOT(1,1),Y1(1,1) ), ( YNAME(1,1),YNAME1(1,1) ),   00000150
     1            ( FPLOT(1,2),Y2(1,1) ), ( YNAME(1,2),YNAME2(1,1) ),   00000160
     2            ( FPLOT(1,3),Y3(1,1) ), ( FPLOT(1,7),Y4(1,1) ),       00000170
     3            ( DEG(1)   ,DEG2(1,1) ), ( DEG(851)   ,DEG1(1) )      00000180
      DATA YNAME(19,1 )/'     '/, YNAME(20,1 )/'     '/                 00000190
      DATA YNAME(19,2 )/'     '/, YNAME(20,2 )/'     '/                 00000200
      DATA YNAME(19,3 )/'     '/, YNAME(20,3 )/'     '/                 00000210
      DATA YNAME(19,4 )/'     '/, YNAME(20,4 )/'     '/                 00000220
      DATA YNAME(19,5 )/'     '/, YNAME(20,5 )/'     '/                 00000230
      DATA YNAME(19,6 )/'     '/, YNAME(20,6 )/'     '/                 00000240
      DATA YNAME(19,7 )/'     '/, YNAME(20,7 )/'     '/                 00000250
      DATA YNAME(19,8 )/'     '/, YNAME(20,8 )/'     '/                 00000260
      DATA YNAME(19,9 )/'     '/, YNAME(20,9 )/'     '/                 00000270
      DATA YNAME(19,10)/'     '/, YNAME(20,10)/'     '/                 00000280
      DATA YNAME(19,11)/'     '/, YNAME(20,11)/'     '/                 00000290
      DATA YNAME(19,12)/'     '/, YNAME(20,12)/'     '/                 00000300
      DATA YNAME(19,13)/'     '/, YNAME(20,13)/'     '/                 00000310
      IP = 0                                                            00000320
      LINES = 80*IP + 1                                                 00000330
      NTIME = 850                                                       00000340
      IGU = YES                                                         00000350
      IGU = NO                                                          00000360
      SCALE =  1.1D0                                                    00000370
      CALL THESIS(FPLOT, DEG, DEG1, DEG2, NTIME, LINES, IP, GRID, Y1,   00000380
     1            Y2, Y3, Y4, YNAME, YNAME1, YNAME2, IGU, SCALE)        00000390
      STOP                                                              00000400
      END                                                               00000410
```

```
      SUBROUTINE AGT(Q, QR4, WT, WTR4, XZERO, ROCKER, NPRINT, AGTLTH,    00000010
     2          REALTH, C, IUNIT, KAGT)                                 00000020
C                                                                        00000030
      IMPLICIT REAL*8(A-H,O-Z)                                           00000040
C                                                                        00000050
      REAL*4 QR4, WTR4 , RXZERO,RAMP,RRPM, DIFF                          00000060
C                                                                        00000070
      INTEGER YES, C                                                     00000080
C                                                                        00000090
      DIMENSION Q(1), QR4(1), AGTLTH(1), REALTH(1)                       00000100
C                                                                        00000110
      COMMON NUNIT, IPRINT                                               00000120
      DATA YES/4HYES /, NO/4HNO  /                                       00000130
C                                                                        00000140
 5001 FORMAT(5E15.7)                                                     00000150
 5002 FORMAT(5E15.7, I3)                                                 00000160
C                                                                        00000170
CC                ****************************************             00000180
CC                **                                    **             00000190
CC                **        OUTPUT PACKAGE FOR AGT      **             00000200
CC                **          CONVERT TO REAL * 4        **             00000210
CC                **                                    **             00000220
CC                ****************************************             00000230
C                                                                        00000240
      IF(KAGT .NE. 1)  GO TO 10                                          00000250
      S = REALTH(2) / AGTLTH(2)                                          00000260
      THETA = DARSIN( XZERO/REALTH(2) )                                  00000270
      DIFF = DABS( Q(7) - Q(10) )                                        00000280
      WRITE(IUNIT,5001) DIFF                                             00000290
C                                                                        00000300
   10 QR4(1)   =     Q(1) - XZERO                                        00000310
      QR4(2)   =     Q(2) - XZERO                                        00000320
      QR4(8)   =     Q(8) - XZERO                                        00000330
      QR4(9)   =     Q(9) - XZERO                                        00000340
      QR4(4)   =     Q(4) + XZERO*ROCKER                                 00000350
      QR4(7)   =     Q(7) - XZERO*ROCKER                                 00000360
      QR4(3)   =   ( Q(3) + THETA )*S                                    00000370
      QR4(5)   =   ( Q(5) + THETA )*S                                    00000380
      QR4(6)   =   ( Q(6) + THETA )*S                                    00000390
      WTR4   =  WT                                                       00000400
C                                                                        00000410
      WRITE(IUNIT,5001) (QR4(JA), JA   =  1,5)                           00000420
      WRITE(7    ,5002) (QR4(JA), JA   =  6,9), OMEGA(I), CONFIG(I)      00000430
C                                                                        00000440
      RETURN                                                             00000450
      END                                                                00000460
```

```
      SUBROUTINE ARRAY(F, Q, QD, QDD, NDEG, FPLOT, NTIME)                00000010
C                                                                        00000020
      IMPLICIT REAL*8(A-H,O-Z)                                           00000030
C                                                                        00000040
      REAL*4 FPLOT                                                       00000050
C                                                                        00000060
      INTEGER YES                                                        00000070
C                                                                        00000080
      DIMENSION F(1), Q(1),QD(1),QDD(1),FPLOT(NTIME,1)                   00000090
C                                                                        00000100
      COMMON NUNIT, IPRINT                                               00000110
C                                                                        00000120
      DATA YES/4HYES /, NO/4HNO  /                                       00000130
C                                                                        00000140
CC                                                                       00000150
      FPLOT(NDEG,1 ) = Q(2) - Q(8)                                       00000160
      FPLOT(NDEG,2 ) = Q(1) - Q(9)                                       00000170
      FPLOT(NDEG,3 ) = Q(9)                                              00000180
      FPLOT(NDEG,4 ) = Q(1)                                              00000190
      FPLOT(NDEG,5 ) = F(1)                                              00000200
      FPLOT(NDEG,6 ) = Q(1) - Q(8)                                       00000210
      FPLOT(NDEG,7 ) = Q(7)                                              00000220
      FPLOT(NDEG,8 ) = Q(10)                                             00000230
      FPLOT(NDEG,9 ) = F(2)                                              00000240
      FPLOT(NDEG,10) = Q(7) + Q(4)                                       00000250
      FPLOT(NDEG,11) = F(7)                                              00000260
C                                                                        00000270
      RETURN                                                             00000280
      END                                                                00000290
```

```
      SUBROUTINE BKSTEP( BMIV, DA, DV, W, WT, SYSM, DAMP, STF, C, NPRINT00000010
     1,                  KSYS, KPRINT, DP, QP, QDP, QDDP, ALFA, BETA,  00000020
     2                   CONFIG, FP, ICORD, NCLEAR, AMP, XZERO, DTPM, DT,  00000030
     3                   ISYS, NC, AMPW, W2, KSYSM1, KSYSM2, DTW, NSYS,  00000040
     4                   IDT, PIN2$8, IDIM, IQ, COLM, COLC, COLK, IDP,  00000050
     5                   QSAV, QDSAV, QDDSAV, FSAV, LAYER, ICHNG, IGU,  00000060
     6                   SCALE)                                         00000070
C                                                                       00000080
      IMPLICIT REAL*8(A-H,O-Z)                                          00000090
C                                                                       00000100
      INTEGER CONFIG(16,1), YES, C, PIN2$8                              00000110
C                                                                       00000120
      DIMENSION BMIV(KSYS,KSYS), DA(KSYS,KSYS), DV(KSYS,KSYS),          00000130
     1          SYSM(KSYS,KSYS,1), DAMP(KSYS,KSYS,1), STF(KSYS,KSYS,1), 00000140
     2          DP(1), FP(1), QP(1), QDP(1), QDDP(1), ALFA(1),          00000150
     3          BETA(1), ICORD(NCLEAR,1), IDIM(1), IQ(KSYS,1)           00000160
      DIMENSION QSAV(1), QDSAV(1), QDDSAV(1), FSAV(1), IDP(KSYS,1),     00000170
     1          COLM(KSYS,1), COLC(KSYS,1), COLK(KSYS,1), LAYER(1)      00000180
C                                                                       00000190
      COMMON NUNIT, IPRINT                                              00000200
C                                                                       00000210
      DATA YES/4HYES /, NO/4HNO  /                                      00000220
C                                                                       00000230
 5000 FORMAT(' ',10X,'FROM BKSTEP', 10X, 'PARTIAL DT =', 1PD15.7, 10X,  00000240
     1       ' PARTIAL WT =', D15.7)                                    00000250
 5001 FORMAT(' ',  5X, 'BACKSTEP REQUIRED ', I4, ' INTERATIONS TO ',    00000260
     1       'REACH A POSITIVE/ZERO FORCE BETWEEN COORD. ', I2, ' AND ',00000270
     2       I2, '   (C=', I2, ')'  )                                   00000280
 5002 FORMAT('0', 10X, 'IN SUBROUTINE BKSTEP; NEGATIVE FORCE DETECTED ',00000290
     1       '- - NEW C CHANGED TO', I2, ' FROM ', I2)                  00000300
 5003 FORMAT(' ', 'FSAV' ,8(1PD15.7,1X) )                               00000310
 5004 FORMAT(' ', '  QSAV',10(1PD12.4) )                                00000320
 5005 FORMAT(' ', ' QDSAV',10(1PD12.4) )                                00000330
 5006 FORMAT(' ', 'QDDSAV',10(1PD12.4) )                                00000340
 5007 FORMAT(' ', 10X, ' DTPM = ', 1PD15.7, '  DTPMW =', D15.7, '  WT=',00000350
     1       D15.7, '  DELWT=', D15.7, '  DELDT=', D15.7)               00000360
 5008 FORMAT(' ', 10X, ' CAMQ = ', 1PD15.7, '  CAMQD =', D15.7, '  CAMQD00000370
     1D=',    D15.7)                                                    00000380
 5009 FORMAT(' ', 10X, ' DTPM = ', 1PD15.7, '      C =', I2)            00000390
 5010 FORMAT(' ',      'C=', I2, '  FORCE =', 1P8D15.7)                 00000400
 5011 FORMAT(' ',  3X, '  FORCE =', 1P8D15.7)                           00000410
 5012 FORMAT(' ',  4X, 'BACKSTEP REQUIRED ', I4, ' INTERATIONS TO ',    00000420
     1       'REACH A POSITIVE/ZERO DISPLACEMENT BETWEEN COORD. ',I2,   00000430
     2       ' AND ', I2, '   (C=', I2, ')'  )                          00000440
 5013 FORMAT(' ', '      DISPL DIFF. AT COORD 1 =', 1PD15.7,            00000450
     1       ' ', '      DISPL DIFF. AT COORD 2 =', 1PD15.7,            00000460
```

```
     2                ' DISPL DIFF. AT COORD 7 =', 1PD15.7)                    00000470
 5014 FORMAT(' ', 'DEGREES=',F9.3,'  CSAVE=',I2,'   C=',I2,                    00000480
     1       ' DISPL 1,2,7=', 1P3D11.3, '  FORCES 1,2,7 =',3D11.3)           00000490
 5017 FORMAT('0', 10X, ' VALUES CALCULATED AFTER BACKSTEP TAKEN:')            00000500
C                                                                             00000510
      EPS1 = 1.0D-1                                                           00000520
      EPS2 = 1.0D-6                                                           00000530
C                                                                             00000540
      PI = 3.1415926535900D0                                                  00000550
      DEGOPI = 180.0D0/PI                                                     00000560
C                                                                             00000570
      IK = 0                                                                  00000580
      DTPMW = DTPM*W                                                          00000590
      DELWT = DTPMW/ 500.0D0                                                  00000600
      WT = WT + DTPMW - DTW                                                   00000610
      WTSAV = WT                                                              00000620
      DELDT = DELWT/W                                                         00000630
C                                                                             00000640
      IF(NPRINT .EQ. YES)                                                     00000650
     1       WRITE(6,5007)  DTPM, DTPMW, WT, DELWT, DELDT                     00000660
C                                                                             00000670
CCCCCC                ********************************************          00000680
CCCCCC                **                                        **          00000690
CCCCCC                **          SAVE  OLD  PARAMETERS         **          00000700
CCCCCC                **                                        **          00000710
CCCCCC                ********************************************          00000720
C                                                                             00000730
    4 DO 5 JA = 1,KSYS                                                        00000740
      FP(JA) = FSAV(JA)                                                       00000750
    5 CONTINUE                                                                00000760
C                                                                             00000770
      DO  15 JA = 1,NSYS                                                      00000780
       CALL ADJUST(JA,JA,QP,QDP,QDDP,QSAV,QDSAV,QDDSAV)                       00000790
   15 CONTINUE                                                                00000800
C                                                                             00000810
      IF(NPRINT .EQ. NO)  GO TO 20                                            00000820
      WRITE(6,5003)  (  FSAV(JA), JA = 1, KSYS)                               00000830
      WRITE(6,5004)  (  QSAV(JA), JA = 1, NSYS)                               00000840
      WRITE(6,5005)  ( QDSAV(JA), JA = 1, NSYS)                               00000850
      WRITE(6,5006)  (QDDSAV(JA), JA = 1, NSYS)                               00000860
C                                                                             00000870
   20 IF(NPRINT .EQ. YES) WRITE(NUNIT,5000) DTPM, WT                          00000880
      IK = IK + 1                                                             00000890
C                                                                             00000900
      CALL CAM(WT, AMP, AMPW, XZERO, W2, QP, QDP, QDDP)                       00000910
C                                                                             00000920
      IF(NPRINT .EQ. YES)                                                     00000930
     1       WRITE(6,5008)  QP(9), QDP(9), QDDP(9)                            00000940
```

```
C
      CALL DEL( DTPM, DTO2, DT2O3, DT2O6, BMIV, DA, DV, SYSM(1,1,C),
     1          DAMP(1,1,C), STF(1,1,C), ISYS, C, NPRINT, KSYS, KPRINT)
C
      IF(NPRINT .EQ. YES)
     1          WRITE(6,5009)  DTPM, C
C
      CALL BRANCH(C, FP, KSYS, ISYS, QP, QDP, QDDP, QDP, ICORD, DT,
     1            NPRINT, NCLEAR, 0, PIN2$8, IDIM)
C
      IF(NPRINT .EQ. YES)
     1          WRITE(6,5010)  C,  (FP(JA), JA= 1,KSYS)
C
      CALL NEWMRK( ISYS, KSYS, C, STF, DAMP, SYSM, DP, DTPM, DTO2,
     1             DT2O6, DT2O3, QP, QDP, QDDP, BMIV, DA, DV, NC, ALFA,
     2             BETA, CONFIG, FP, ICORD, NCLEAR, NPRINT, IQ, COLM,
     3           COLC, COLK, IDP, PIN2$8, IDIM, LAYER, IGU, QDDSAV,
     4             QDSAV, QSAV, 0.0, 0)
      IF(NPRINT .EQ. YES)
     1          WRITE(6,5011)       (FP(JA), JA= 1,KSYS)
C
      DISPL1 = QP(1) - QP(9)
      DISPL2 = QP(2) - QP(8)
      DISPL7 = QP(7) - QP(10)
C
      IF(NPRINT .EQ. YES)
     1          WRITE(NUNIT,5013) DISPL1,  DISPL2, DISPL7
C
      INDEX = ICORD(IDT,1)
      NDEX = ICORD(IDT,2)
      IF(CONFIG(C,IDT) .EQ. 0)  GO TO 25
C
      IF(FP(INDEX) .GE. 0.0  )  GO TO 24
      GO TO 30
C
   24 IF(KPRINT .EQ. YES  .AND.  IK .GT. 1)
     1     WRITE(NUNIT,5001) IK, INDEX, NDEX, C
      GO TO 40
C
C
```

```
   25 DISPL = QP(INDEX) - QP(NDEX)                                          00001350
                                                                            00001360
C                                                                           00001370
      IF(DISPL .GE. 0.0)  GO TO 28                                          00001380
      IF( DABS(DISPL) .LE. EPS2)     GO TO 28                               00001390
      GO TO 30                                                              00001400
C                                                                           00001410
   28 IF(KPRINT .EQ. YES  .AND.  IK .GT. 1)                                 00001420
     1     WRITE(NUNIT,5012) IK, INDEX, NDEX, C                             00001430
      GO TO 40                                                              00001440
C                                                                           00001450
C                                                                           00001460
C                                                                           00001470
   30 DTPM = DTPM - DELDT                                                   00001480
      WT = WT - DELWT                                                       00001490
C                                                                           00001500
      IF(WT .LE. WTSAV)  RETURN                                             00001510
C                                                                           00001520
      GO TO 4                                                               00001530
C                                                                           00001540
   40 CONTINUE                                                              00001550
C                                                                           00001560
      DEGR = WT*DEGOPI                                                      00001570
      NDEG = DEGR                                                           00001580
C                                                                           00001590
      WRITE(NUNIT,5014) DEGR,C,ICHNG,DISPL1,DISPL2,DISPL7,                  00001600
     1                  FP(1), FP(2), FP(7)                                 00001610
      IF(NPRINT .EQ. NO)  RETURN                                            00001620
C                                                                           00001630
C                                                                           00001640
      WRITE(NUNIT,5017)                                                     00001650
C                                                                           00001660
      CALL DEBUG( 2, Q, QD, QDD, F, KSYS, ISYS, DP, NDEG, NPRINT, DEGR,     00001670
     1            C)                                                        00001680
C                                                                           00001690
      RETURN                                                                00001700
      END
```

```
      SUBROUTINE BRANCH(C,F,KSYS,ISYS,Q,QD,QDD,QDSAV,ICORD,DT,
     1                  NPRINT, NCLEAR, IMP, PIN2$8, IDIM)
C
      IMPLICIT REAL*8(A-H,O-Z)
C
      INTEGER YES, C, PIN2$8
C
      DIMENSION Q(1), QD(1), QDD(1),QDSAV(1), F(1), ICORD(NCLEAR,1),
     1          IDIM(1)
C
      COMMON NUNIT, IPRINT
C
      DATA YES/4HYES /, NO/4HNO  /
C
    5 ISYS = IDIM(C)
C
      GO TO (  10, 20,  30, 40, 50, 60, 70, 80), C
C
C     CONFIGURATION - I - NO CONTACT
   10 F(1) = 0.0D0
      F(2) = 0.0D0
      F(7) = 0.0D0
      GO TO 100
C
CC
C     CONFIGURATION -II - CONTACT AT VALVE SEAT
   20 CONTINUE
      CALL ADJUST(7,10, Q, QD, QDD, Q, QD, QDD)
C
      F(1) = 0.0D0
      F(2) = 0.0D0
      GO TO 100
C
CC
C     CONFIGURATION - III - CONTACT AT ROCKER
   30 F(1) = 0.0D0
      F(7) = 0.0D0
      GO TO 100
C
CC
C     CONFIGURATION -  IV - CONTACT AT ROCKER AND VALVE SEAT
   40 CONTINUE
C
      CALL ADJUST(7,10, Q, QD, QDD, Q, QD, QDD)
C
      F(1) = 0.0D0
```

```
      GO TO 100                                                          00000470
                                                                         00000480
C                                                                        00000490
CC                                                                       00000500
CCC                                                                      00000510
C     CONFIGURATION - V -CONTACT AT CAM                                  00000520
   50 CONTINUE                                                           00000530
C                                                                        00000540
      CALL ADJUST(1,9, Q, QD, QDD, Q, QD, QDD)                           00000550
C                                                                        00000560
      F(2) = 0.0D0                                                       00000570
      F(7) = 0.0D0                                                       00000580
      GO TO 100                                                          00000590
C                                                                        00000600
CC                                                                       00000610
CCC                                                                      00000620
C     CONFIGURATION -VI -CONTACT AT CAM AND VALVE SEAT                   00000630
   60 CONTINUE                                                           00000640
C                                                                        00000650
      CALL ADJUST(1,9, Q, QD, QDD, Q, QD, QDD)                           00000660
      CALL ADJUST(7,10, Q, QD, QDD, Q, QD, QDD)                          00000670
C                                                                        00000680
      F(2) = 0.0D0                                                       00000690
      GO TO 100                                                          00000700
C                                                                        00000710
CC                                                                       00000720
CCC                                                                      00000730
C     CONFIGURATION - VII - CONTACT AT ROCKER AND CAM                    00000740
   70 CONTINUE                                                           00000750
C                                                                        00000760
      CALL ADJUST(1,9, Q, QD, QDD, Q, QD, QDD)                           00000770
C                                                                        00000780
      F(7) = 0.0D0                                                       00000790
      GO TO 100                                                          00000800
C                                                                        00000810
CC                                                                       00000820
CCC                                                                      00000830
C     CONFIGURATION - VIII - CONTACT AT ROCKER, CAM, AND VALVE SEAT      00000840
   80 CONTINUE                                                           00000850
C                                                                        00000860
      CALL ADJUST(1,9, Q, QD, QDD, Q, QD, QDD)                           00000870
      CALL ADJUST(7,10, Q, QD, QDD, Q, QD, QDD)                          00000880
C                                                                        00000890
  100 CONTINUE                                                           00000900
      IF(IMP .NE. 0)  QDD(IMP) = ( QD(IMP)-QDSAV(IMP) ) / DT             00000910
C                                                                        00000920
      RETURN                                                             00000930
      END
```

```
      SUBROUTINE CONMAT(NC, CONFIG, IDP, NPRINT, KSYS)                  00000010
C                                                                       00000020
      IMPLICIT REAL*8(A-H,O-Z)                                          00000030
C                                                                       00000040
      INTEGER CONFIG(16,4), CSAVE, TWON, TWONP1, YES                    00000050
C                                                                       00000060
      DIMENSION IDP(KSYS,1)                                             00000070
C                                                                       00000080
      COMMON NUNIT, IPRINT                                              00000090
C                                                                       00000100
      DATA  YES/4HYES /, NO/4HNO  /                                     00000110
C                                                                       00000120
CCCCCCCCC                                                               00000130
C             ****************************************                  00000140
C             **                                    **                  00000150
C             **                                    **                  00000160
C             **       ESTABLISH CONFIGURATION      **                  00000170
C             **                MATRIX              **                  00000180
C             **                                    **                  00000190
C             ****************************************                  00000200
C                                                                       00000210
  100 NC = 4                                                            00000220
      TWON = 2**NC                                                      00000230
      TWONP1 = TWON + 1                                                 00000240
      NCM1 = NC - 1                                                     00000250
      NCM2 = NC - 2                                                     00000260
      NCM3 = NC - 3                                                     00000270
C                                                                       00000280
      DO  110  I = 2,TWON,2                                             00000290
      CONFIG(I,NC) = 1                                                  00000300
  110 CONTINUE                                                          00000310
C                                                                       00000320
      DO  120  I = 2,TWON,4                                             00000330
      CONFIG(I+1,NCM1) = 1                                              00000340
      CONFIG(I+2,NCM1) = 1                                              00000350
  120 CONTINUE                                                          00000360
C                                                                       00000370
      DO 130 I = 1,NC                                                   00000380
      CONFIG(I+4,NCM2) = 1                                              00000390
      CONFIG(I+12,NCM2) = 1                                             00000400
  130 CONTINUE
```

```
C                ********************************************
C                **                                          **
C                **                ESTABLISH                 **
C                **              MATRIX   IDP                **
C                **                                          **
C                ********************************************
      DO  140  JA = 1,KSYS
C
      IDP(JA,1) = CONFIG(JA,2)
      IDP(JA,2) = 0
      IDP(JA,3) = CONFIG(JA,4) * 7
C
  140 CONTINUE
C
C     NC = 8
C
      RETURN
      END
```

00000410
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```
      SUBROUTINE DEBUG(IBLOCK, Q, QD, QDD, F, KSYS, ISYS, DP, NDEG,      00000010
     1                 NPRINT, DEGR, C)                                  00000020
C                                                                        00000030
      IMPLICIT REAL*8(A-H,O-Z)                                           00000040
C                                                                        00000050
      INTEGER YES, C                                                     00000060
C                                                                        00000070
      DIMENSION Q(10), QD(10), QDD(10), F(10), DP(8)                     00000080
C                                                                        00000090
      COMMON NUNIT, IPRINT                                               00000100
C                                                                        00000110
      DATA YES/4HYES /, NO/4HNO  /                                       00000120
C                                                                        00000130
 5001 FORMAT(' ','**************************************************',  00000140
     1'**************************************************')             00000150
 5002 FORMAT(' ','Q    ',1P7D16.7, D15.7)                               00000160
 5003 FORMAT(' ','QD   ',1P7D16.7, D15.7)                               00000170
 5004 FORMAT(' ','QDD  ',1P7D16.7, D15.7)                               00000180
 5005 FORMAT(' ','DEL P',1P7D16.7, D15.7)                               00000190
 5007 FORMAT(' ',' ',' DISPL DIFF. AT COORD 1 =', 1PD15.7,              00000200
     1           ' ',' DISPL DIFF. AT COORD 2 =', 1PD15.7,              00000210
     2           ' ',' DISPL DIFF. AT COORD 7 =', 1PD15.7)              00000220
 5037 FORMAT(' ','FORCE',1P7D16.7, D15.7)                               00000230
 5061 FORMAT(' ', 16X,I5,'  DEGREES =',  F9.3, 15X, 'CONFIGURATION ',I2) 00000240
 5063 FORMAT(' ','CAMQ=',1PD16.7, 11X,'CAMQD =', D16.8, 10X,'CAMQDD =',  00000250
     1    D16.8)                                                         00000260
C                                                                        00000270
      DISPL1 = Q(1) - Q(9)                                               00000280
      DISPL2 = Q(2) - Q(8)                                               00000290
      DISPL7 = Q(7) - Q(10)                                              00000300
      GO TO(1,2,3,4,5), IBLOCK                                           00000310
C                                                                        00000320
    1 CONTINUE                                                           00000330
      WRITE(NUNIT,5061) NDEG,  DEGR, C                                   00000340
      WRITE(NUNIT,5007) DISPL1,  DISPL2,  DISPL7                         00000350
      WRITE(NUNIT,5063) Q(9), QD(9), QDD(9)                              00000360
      WRITE(NUNIT,5002) (  Q(JA), JA = 1, KSYS )                         00000370
      WRITE(NUNIT,5003) ( QD(JA), JA = 1, KSYS )                         00000380
      WRITE(NUNIT,5004) (QDD(JA), JA = 1, KSYS )                         00000390
      WRITE(NUNIT,5037) (  F(JA), JA = 1, KSYS )                         00000400
      IF(NPRINT .EQ. YES)  WRITE(NUNIT,5001)                             00000410
C                                                                        00000420
      RETURN                                                             00000430
C                                                                        00000440
C                                                                        00000450
C                                                                        00000460
```

```
      2  CONTINUE                                                        00000470
         IF(NDEG .GT. 200)  NPRINT = YES                                 00000480
         WRITE(NUNIT,5061) NDEG,  DEGR, C                                00000490
         WRITE(NUNIT,5007) DISPL1,  DISPL2,  DISPL7                      00000500
         WRITE(NUNIT,5063) Q(9), QD(9), QDD(9)                           00000510
         WRITE(NUNIT,5002) (  Q(JA), JA = 1, KSYS )                      00000520
         WRITE(NUNIT,5003) ( QD(JA), JA = 1, KSYS )                      00000530
         WRITE(NUNIT,5004) (QDD(JA), JA = 1, KSYS )                      00000540
         WRITE(NUNIT,5037) (  F(JA), JA = 1, KSYS )                      00000550
C                                                                        00000560
         RETURN                                                          00000570
C                                                                        00000580
CC                                                                       00000590
      3  CONTINUE                                                        00000600
C                                                                        00000610
         RETURN                                                          00000620
C                                                                        00000630
CC                                                                       00000640
      4  CONTINUE                                                        00000650
C                                                                        00000660
         RETURN                                                          00000670
C                                                                        00000680
CC                                                                       00000690
      5  CONTINUE                                                        00000700
C                                                                        00000710
         RETURN                                                          00000720
         END                                                             00000730
```

```
      SUBROUTINE DEL( DT, DT02, DT203, DT206, BMIV, DA, DV, EM,          00000010
     1 SE, CA, KS, C, NPRINT, KSYS, KPRINT)                              00000020
C                                                                        00000030
      IMPLICIT REAL*8(A-H,O-Z)                                           00000040
C                                                                        00000050
      INTEGER YES, C                                                     00000060
C                                                                        00000070
      DIMENSION BMIV( KSYS,KSYS), DA( KSYS,KSYS), DV( KSYS,KSYS)         00000080
      DIMENSION   EM( KSYS,KSYS), SE( KSYS,KSYS), CA( KSYS,KSYS)         00000090
C                                                                        00000100
      COMMON NUNIT, IPRINT                                               00000110
      DATA YES/4HYES /, NO/4HNO  /                                       00000120
C                                                                        00000130
 1000 FORMAT('0',5X,'DT =' 1PD12.5,'  DT/2 =',D12.3,                     00000140
     1'  DT**2/3 =',D12.3,'  DT**2/6 =',D12.3)                           00000150
C                                                                        00000160
      DT02  = DT*0.5D0                                                   00000170
      DT203 = DT**2/3.0D0                                                00000180
      DT206 = DT203*0.5D0                                                00000190
C                                                                        00000200
      IF(NPRINT .EQ. NO) GO TO 10                                        00000210
      WRITE(NUNIT,1000) DT, DT02, DT203, DT206                           00000220
C                                                                        00000230
   10 DO 20  JA = 1, KS                                                  00000240
C                                                                        00000250
      DO 20  JB = 1, KS                                                  00000260
      BMIV(JA,JB) = EM(JA,JB) + DT02*SE(JA,JB) + DT206*CA(JA,JB)         00000270
C                                                                        00000280
   20 CONTINUE                                                           00000290
C                                                                        00000300
      CALL DINVS( BMIV, KS,KSYS)                                         00000310
C                                                                        00000320
      DO 30  JA = 1, KS                                                  00000330
C                                                                        00000340
      DO 30  JB = 1, KS                                                  00000350
      DA( JA, JB) = 0.0D0                                                00000360
      DV( JA, JB) = 0.0D0                                                00000370
C                                                                        00000380
      DO 30  JC = 1, KS                                                  00000390
      DA( JA, JB) = DA( JA, JB) + BMIV( JA, JC)*SE( JC, JB)              00000400
      DV( JA, JB) = DV( JA, JB) + BMIV( JA, JC)*CA( JC, JB)              00000410
C                                                                        00000420
   30 CONTINUE                                                           00000430
C                                                                        00000440
      RETURN                                                             00000450
      END                                                                00000460
```

```
C
CC-----------------------------------------------------------------
CCC
CCC                SUBROUTINE CODED BY DR. R. C. WINFREY
CCC                     MODIFIED BY C. W. GNILKA
CCC
CC-----------------------------------------------------------------
C
      SUBROUTINE  DINVS(A,NMAX,KSYS)                                    00000010
C                                                                       00000020
      IMPLICIT REAL*8(A-H,O-Z)                                          00000030
      INTEGER YES                                                       00000040
C                                                                       00000050
      DIMENSION A(KSYS,KSYS)                                            00000060
C                                                                       00000070
      COMMON NUNIT, IPRINT                                              00000080
C                                                                       00000090
      DATA  YES/4HYES /, NO/4HNO  /                                     00000100
C                                                                       00000110
      DO 200 N=1,NMAX                                                   00000120
      D=A(N,N)                                                          00000130
C                                                                       00000140
      IF(D.EQ.0.) GO TO 300                                             00000150
C                                                                       00000160
      DO 100 J=1,NMAX                                                   00000170
  100 A(N,J)=-A(N,J)/D                                                  00000180
C                                                                       00000190
      DO 150 I=1,NMAX                                                   00000200
      IF(N-I) 110,150,110                                               00000210
C                                                                       00000220
  110 DO 140 J=1,NMAX                                                   00000230
      IF(N-J) 120,140,120                                               00000240
C                                                                       00000250
  120 A(I,J)=A(I,J)+A(I,N)*A(N,J)                                       00000260
  140 CONTINUE                                                          00000270
C                                                                       00000280
  150 A(I,N)=A(I,N)/D                                                   00000290
      A(N,N)=1.0/D                                                      00000300
  200 CONTINUE                                                          00000310
C                                                                       00000320
      RETURN                                                            00000330
  300 WRITE(6,320)  N,D                                                 00000340
  320 FORMAT('0',//,10X,'ERROR RETURN FROM DINVS.  MATRIX SINGULAR. ',  00000350
     1  'DIAGONL ELEMENT' ,I4,3H = ,1PD20.12)                            00000360
C                                                                       00000370
      RETURN                                                            00000380
      END                                                               00000390
```

```
C                                                                       00000010
C-----------------------------------------------------------------------00000020
C                                                                       00000030
C      THE FOLLOWING PLOT SUBROUTINES CODED BY DR. R. C. WINFREY        00000040
C                                                                       00000050
C-----------------------------------------------------------------------00000060
C                                                                       00000070

      SUBROUTINE DRUP(X,Y,K,N,XSIZE,YSIZE,NPT,LABEL,TITLE,XNAME,YNAME)  00000080
      DIMENSION TITLE(1),XNAME(1),YNAME(20,1),LABEL(1)                  00000090
      DIMENSION X(1),Y(N,1)                                             00000100
      CALL       DRUBL(X,Y,K,N,XSIZE,YSIZE,NPT,LABEL,TITLE,XNAME,YNAME) 00000110
C                                                                       00000120
      RETURN                                                            00000130
      END                                                               00000140
C                                                                       00000150
CCCCC                                                                   00000160
CCCCC                                                                   00000170
CCCCC                                                                   00000180
C                                                                       00000190


      SUBROUTINE DRUPB(X,Y,K,N,XSIZE,YSIZE,NPT,LABEL,TITLE,XNAME,YNAME) 00000200
      DIMENSION TITLE(1),XNAME(1),YNAME(20,1),LABEL(1)                  00000210
      DIMENSION X(1),Y(N,1)                                             00000220
      CALL       DRUB(X,Y,K,N,XSIZE,YSIZE,NPT,LABEL,TITLE,XNAME,YNAME)  00000230
C                                                                       00000240
      RETURN                                                            00000250
      END                                                               00000260
C                                                                       00000270
CCCCC                                                                   00000280
CCCCC                                                                   00000290
CCCCC                                                                   00000300
C                                                                       00000310


      SUBROUTINE DRUBL(X,Y,K,N,XSIZE,YSIZE,NPT,LABEL,TITLE,XNAME,YNAME) 00000320
      DIMENSION TITLE(1),XNAME(1),YNAME(20,1),LABEL(1)                  00000330
      DIMENSION X(1),Y(N,1),YMIN(20),DY(20)                             00000340
      PAPER=11.                                                         00000350
      CALL PLOTS                                                        00000360
      CALL PLOT(-11.,0.,-3)                                             00000370
      CALL SYMBOL(0.,0.,.14,LABEL,0.,80)                                00000380
      CALL PLOT(0.,4.,-3)                                               00000390
      NSIGN=1                                                           00000400
      IF(NPT.LT.0) NSIGN=-1                                             00000410
      NPA=NPT*NSIGN                                                     00000420
```

```
      XST=FLOAT(K)*.65                                                  00000430
      XSTP=XST+(PAPER-XSIZE)*.5                                         00000440
      IF(XSIZE.GT.8.01) XSTP=XST+1.                                     00000450
      XAXIS=XSIZE-XST                                                   00000460
      CALL SCALE(X,N,1,XAXIS,0.,XMIN,DX)                                00000470
      DO 100 JA=1,K                                                     00000480
      CALL SCALE(Y(1,JA),N,1,YSIZE,0.,YMIN(JA),DY(JA))                  00000490
  100 CONTINUE                                                          00000500
      DO 130 JA=1,N                                                     00000510
  130 X(JA)=X(JA)+XSTP                                                  00000520
      YMAX=YMIN(1)+DY(1)*YSIZE                                          00000530
      YS=ABS(YMIN(1))/DY(1)                                             00000540
      IF(YMAX.LT.0.) YS=0.                                              00000550
      IF(YMIN(1). GT.0.) YS=0.                                          00000560
      IF(XSIZE.GT.8.01) GO TO 200                                       00000570
      CALL CENT(XNAME,NTT)                                              00000580
      NLT=-NTT                                                          00000590
      CALL EXISA(XSTP,YS,XNAME,NLT,XAXIS,0.,XMIN,DX)                    00000600
      CALL EXISA(XSTP,YS,XNAME,NLT,XAXIS,0.,XMIN,DX)                    00000610
      JB=1                                                              00000620
      DO 160 JA=1,K                                                     00000630
      JB=JB+1                                                           00000640
      IF(JB.EQ.8) JB=2                                                  00000650
      YST=XSTP-.65*FLOAT(JA-1)                                          00000660
      CALL CENT(YNAME(1,JA),NTT)                                        00000670
      CALL EXISA(YST,0.,YNAME(1,JA),NTT,YSIZE,90.,YMIN(JA),DY(JA))      00000680
      JC=NPT                                                            00000690
      IF(NPA.EQ.10) JC=JB*NSIGN                                         00000700
      CALL LIND(X,Y(1,JA),N,1,JC)                                       00000710
      CALL LIND(X,Y(1,JA),N,1,JC)                                       00000720
      CALL LIND(X,Y(1,JA),N,1,JC)                                       00000730
  160 CONTINUE                                                          00000740
      YL=-.8                                                            00000750
      CALL CENT(TITLE,NTT)                                              00000760
      XL=PAPER*.5-FLOAT(NTT/2)*.18                                      00000770
      CALL SYMBOL(XL,  YL,.21,TITLE,0.,NTT)                             00000780
      YAX=YSIZE+3.                                                      00000790
      GO TO 300                                                         00000800
  200 XFAR=(PAPER+YSIZE)*.5                                             00000810
      YS=XFAR-YS                                                        00000820
      CALL CENT(XNAME,NTT)                                              00000830
      NLT=-NTT                                                          00000840
      CALL EXISA(YS,XSTP,XNAME,NLT,XAXIS,90.,XMIN,DX)                   00000850
      JB=1                                                              00000860
      DO 260 JA=1,K                                                     00000870
      JB=JB+1                                                           00000880
      IF(JB.EQ.8) JB=2                                                  00000890
      YST=XSTP-.65*FLOAT(JA-1)                                          00000900
```

```
      CALL CENT(YNAME(1,JA),NTT)                                        00000910
      CALL EXISA(XFAR,YST,YNAME(1,JA),NTT,YSIZE,180.,YMIN(JA),DY(JA))   00000920
      DO 230 JC=1,N                                                     00000930
  230 Y(JC,JA)=XFAR-Y(JC,JA)                                            00000940
      JC=NPT                                                            00000950
      IF(NPA.EQ.10) JC=JB*NSIGN                                         00000960
      CALL LIND(Y(1,JA),X,N,1,JC)                                       00000970
      CALL LIND(Y(1,JA),X,N,1,JC)                                       00000980
      CALL LIND(Y(1,JA),X,N,1,JC)                                       00000990
      DO 260 JC=1,N                                                     00001000
      Y(JC,JA)=XFAR-Y(JC,JA)                                            00001010
  260 CONTINUE                                                          00001020
      XL=XFAR+.8                                                        00001030
      IF(YS.LT..01) XL=XL+.55                                           00001040
      CALL CENT(TITLE,NTT)                                              00001050
      YL=XSIZE*.5+1.-FLOAT(NTT/2)*.18                                   00001060
      CALL SYMBOL(XL,YL,.21,TITLE,90.,NTT)                              00001070
      YAX=XSIZE+3.                                                      00001080
  300 CALL PLOT(0.,YAX,-3)                                              00001090
      CALL SYMBOL(0.,0.,.14,LABEL,0.,80)                                00001100
      CALL PLOT(1.25,4.,-3)                                             00001110
      CALL PLOTE                                                        00001120
      WRITE(6,400)(TITLE(J),J=1,20)                                     00001130
  400 FORMAT(/////20X,75HA PLOT HAS BEEN DRAWN BY SUBROUTINE DRUP CONTAI00001140
     1NING THE FOLLOWING TITLE -      ,////20X,20A4,////)               00001150
C   RESTORE ORIGINAL VALUES OF X AND Y                                  00001160
      DO 420 JA=1,N                                                     00001170
      X(JA)=(X(JA)-XSTP)*DX+XMIN                                        00001180
      DO 420 JB=1,K                                                     00001190
  420 Y(JA,JB)=Y(JA,JB)*DY(JB)+YMIN(JB)                                 00001200
      RETURN                                                            00001210
      END                                                               00001220


      SUBROUTINE EXISA(X,Y,BCD,NC,SIZE,THETA,YMIN,DY)                   00001230
      DIMENSION BCD(1)                                                  00001240
      DATA EPS/1.E-6/                                                   00001250
      ZING=1.                                                           00001260
      IF(NC) 1,2,2                                                      00001270
    1 ZING = -1.                                                        00001280
    2 NAC=IABS(NC)                                                      00001290
      TH=THETA*.0174533                                                 00001300
      N=SIZE+.5                                                         00001310
      CTH=COS(TH)                                                       00001320
      STH=SIN(TH)                                                       00001330
      TN=N                                                              00001340
      XB=X                                                              00001350
      YB=Y                                                              00001360
```

```
C      DRAW AXIS WITH TIC MARKS                                          00001370
       XA=X-.06*ZING*STH                                                 00001380
       YA=Y+.06*ZING*CTH                                                 00001390
       CALL PLOT(XA,YA,3)                                                00001400
       DO 20 I=1,N                                                       00001410
       CALL PLOT(XB,YB,2)                                                00001420
       XC=XB+CTH                                                         00001430
       YC=YB+STH                                                         00001440
       CALL PLOT(XC,YC,2)                                                00001450
       XA=XA+CTH                                                         00001460
       YA=YA+STH                                                         00001470
       CALL PLOT(XA,YA,2)                                                00001480
       XB=XC                                                             00001490
    20 YB=YC                                                             00001500
C       NUMBER THE TIC MARKS                                             00001510
       IF(DY) 22,31,22                                                   00001520
    22 CHAR=ABS(YMIN)                                                    00001530
       ABSV=ABS(YMIN+DY)                                                 00001540
       IF(ABSV-CHAR) 5,6,6                                               00001550
     5 ABSV=CHAR                                                         00001560
     6 POW=0.                                                            00001570
       CALL ANN(ABSV,BBSV,KPOW)                                          00001580
       POW=KPOW                                                          00001590
    93 ADY=DY*10.**(-POW)                                                00001600
       ABSV=YMIN*10.**(-POW)+TN*ADY                                      00001610
       XA=XB-(.18*ZING-.07)*STH-.1714*CTH                                00001620
       YA=YB+(.18*ZING-.07)*CTH-.1714*STH                                00001630
       N=N+1                                                             00001640
       DO 30 I=1,N                                                       00001650
       IF(ABS(ABSV)-EPS) 101,101,100                                     00001660
   100 CALL NUMBER(XA,YA,.14,ABSV,THETA,2)                               00001670
   101 ABSV=ABSV-ADY                                                     00001680
       XA=XA-CTH                                                         00001690
    30 YA=YA-STH                                                         00001700
    31 TNC=NAC+7                                                         00001710
C     WRITE AXIS LABEL                                                   00001720
       XA=X+(SIZE*.5-.06*TNC)*CTH-(-.14+ZING*.46)*STH                    00001730
       YA=Y+(SIZE*.5-.06*TNC)*STH+(-.14+ZING*.46)*CTH                    00001740
       CALL SYMBOL(XA,YA,.14,BCD,THETA,NAC)                              00001750
       XA=XA+((TNC-6.)*.12)*CTH                                          00001760
       YA=YA+((TNC-6.)*.12)*STH                                          00001770
   802 IF(DY) 801,50,801                                                 00001780
   801 IF(POW) 35,50,35                                                  00001790
    35 CALL SYMBOL(XA,YA,.14,7H(X10  ),THETA,7)                          00001800
       XA=XA+.48*CTH-.14*STH                                             00001810
       YA=YA+.48*STH+.14*CTH                                             00001820
       IF(POW) 40,50,40                                                  00001830
    40 CALL NUMBER(XA,YA,.14,POW,THETA,-1)                               00001840
```

```
   50 RETURN                                                              00001850
      END                                                                 00001860

      SUBROUTINE LIND(X,Y,N,K,L)                                          00001870
      DIMENSION X(1),Y(1)                                                 00001880
      DATA IPLUS,ISQ,IDM,ISTAR,ICROSS,IDOT                                00001890
     C  /'+', ZCA000000, ZCB000000, '*', ZCC000000, '.'/                  00001900
      I3=3                                                                00001910
      KK=K                                                                00001920
C...DATA IN EVERY KTH CELL                                                00001930
      IF(K) 5,55,6                                                        00001940
   55 WRITE(6,1000)                                                       00001950
 1000 FORMAT(5X,'PLT CODE 01  K=0 IN ARG LIST FOR SUBROUT. LINE')         00001960
      RETURN                                                              00001970
    5 I3=2                                                                00001980
      KK=-KK                                                              00001990
    6 NP=N*KK                                                             00002000
C...TEST BRANCH VALUE                                                     00002010
      LL=IABS(L)                                                          00002020
      IF(LL)65,65,64                                                      00002030
   64 IF(LL-7) 7,7,65                                                     00002040
   65 LL=1                                                                00002050
    7 DO 10 I=1,NP,KK                                                     00002060
      CALL PLOT(X(I),Y(I),I3)                                             00002070
C...PEN CONDITION BETWEEN POINTS                                          00002080
      IF(L)71,71,73                                                       00002090
   71 I3=3                                                                00002100
      GO TO 199                                                           00002110
   73 I3=2                                                                00002120
C...BRANCH TO SPECIFIED MARKER                                            00002130
  199 GO TO(10,200,300,400,500,600,700),LL                                00002140
  200 IBCD=IPLUS                                                          00002150
      GO TO 9                                                             00002160
  300 IBCD=ISQ                                                            00002170
      GO TO 91                                                            00002180
  400 IBCD=IDM                                                            00002190
      GO TO 9                                                             00002200
  500 IBCD=ISTAR                                                          00002210
      GO TO 9                                                             00002220
  600 IBCD=ICROSS                                                         00002230
      GO TO 91                                                            00002240
  700 IBCD=IDOT                                                           00002250
      XP=X(I)-.03                                                         00002260
      YP=Y(I)-.03                                                         00002270
      GO TO 94                                                            00002280
    9 XP=X(I)-.04                                                         00002290
      YP=Y(I)-.06                                                         00002300
```

```
      GO TO 94                                                          00002310
   91 XP=X(I)-.03                                                       00002320
      YP=Y(I)-.05                                                       00002330
      GO TO 94                                                          00002340
   94 CALL SYMBOL(XP,YP,.14,IBCD,0.,1)                                  00002350
   95 CALL PLOT(X(I),Y(I),3)                                            00002360
   10 CONTINUE                                                          00002370
   11 RETURN                                                            00002380
      END                                                               00002390

      SUBROUTINE CENT(BCD,NTT)                                          00002400
      DIMENSION BCD(1)                                                  00002410
      DATA BLNK/'    '/                                                 00002420
      NTT=0                                                             00002430
      DO 10 JA=1,20                                                     00002440
      JB=JA                                                             00002450
      IF(BCD(JA).NE.BLNK) GO TO 20                                      00002460
   10 CONTINUE                                                          00002470
      RETURN                                                            00002480
   20 JA=20                                                             00002490
   21 IF(BCD(JA).NE.BLNK) GO TO 30                                      00002500
      JA=JA-1                                                           00002510
      IF(JA.LT.0) RETURN                                                00002520
      GO TO 21                                                          00002530
   30 JC=JA                                                             00002540
   40 NTTA=JC-JB+1                                                      00002550
      NTT=4*NTTA                                                        00002560
      DO 50 JA=1,NTTA                                                   00002570
      JD=JA+JB-1                                                        00002580
   50 BCD(JA)=BCD(JD)                                                   00002590
      NTTP=NTTA+1                                                       00002600
      IF(NTTP.GT.20) RETURN                                             00002610
      DO 60 JA=NTTP,20                                                  00002620
   60 BCD(JA)=BLNK                                                      00002630
      RETURN                                                            00002640
      END                                                               00002650

      SUBROUTINE DRUA(X,Y,K,N,XSIZE,YSIZE,NPT)                          00002660
      DIMENSION X(1),Y(N,1),YMIN(20),DY(20)                             00002670
      DIMENSION TITLE(20),XNAME(20),YNAME(20,20)                        00002680
      PAPER=11.                                                         00002690
   50 FORMAT(20A4)                                                      00002700
      READ(5,50,END=400) (TITLE(JA),JA=1,20)                            00002710
      READ(5,50,END=400) (XNAME(JA),JA=1,20)                            00002720
      DO 60 JA=1,K                                                      00002730
      READ(5,50,END=400) (YNAME(JB,JA),JB=1,20)                         00002740
```

```
 60 CONTINUE                                                              00002750
    CALL PLOTS                                                            00002760
    CALL PLOT(-11.,0.,-3)                                                 00002770
    CALL SYMBOL(0.,0.,.21,'BOX 81  WINFREY',0.,15)                        00002780
    CALL PLOT(0.,4.,-3)                                                   00002790
    NSIGN=1                                                               00002800
    IF(NPT.LT.0) NSIGN=-1                                                 00002810
    NPA=NPT*NSIGN                                                         00002820
    XST=FLOAT(K)*.5                                                       00002830
    XSTP=XST+(PAPER-XSIZE)*.5                                             00002840
    IF(XSIZE.GT.8.01) XSTP=XST+1.                                         00002850
    XAXIS=XSIZE-XST                                                       00002860
    CALL SCALE(X,N,1,XAXIS,0.,XMIN,DX)                                    00002870
    DO 100 JA=1,K                                                         00002880
    CALL SCALE(Y(1,JA),N,1,YSIZE,0.,YMIN(JA),DY(JA))                      00002890
100 CONTINUE                                                              00002900
    DO 130 JA=1,N                                                         00002910
130 X(JA)=X(JA)+XSTP                                                      00002920
    YMAX=YMIN(1)+DY(1)*YSIZE                                              00002930
    YS=ABS(YMIN(1))/DY(1)                                                 00002940
    IF(YMAX.LT.0.) YS=0.                                                  00002950
    IF(YMIN(1). GT.0.) YS=0.                                              00002960
    IF(XSIZE.GT.8.01) GO TO 200                                           00002970
    CALL CENT(XNAME,NTT)                                                  00002980
    NLT=-NTT                                                              00002990
    CALL EXIS(XSTP,YS,XNAME,NLT,XAXIS,0.,XMIN,DX)                         00003000
    JB=1                                                                  00003010
    DO 160 JA=1,K                                                         00003020
    JB=JB+1                                                               00003030
    IF(JB.EQ.8) JB=2                                                      00003040
    YST=XSTP-.5*FLOAT(JA-1)                                               00003050
    CALL CENT(YNAME(1,JA),NTT)                                            00003060
    CALL EXIS(YST,0.,YNAME(1,JA),NTT,YSIZE,90.,YMIN(JA),DY(JA))           00003070
    JC=NPT                                                                00003080
    IF(NPA.EQ.10) JC=JB*NSIGN                                             00003090
    CALL LINE(X,Y(1,JA),N,1,JC)                                           00003100
160 CONTINUE                                                              00003110
    YL=-.8                                                                00003120
    CALL CENT(TITLE,NTT)                                                  00003130
    XL=PAPER*.5-FLOAT(NTT/2)*.12                                          00003140
    CALL SYMBOL(XL,  YL,.14,TITLE,0.,NTT)                                 00003150
    YAX=YSIZE+3.                                                          00003160
    GO TO 300                                                             00003170
200 XFAR=(PAPER+YSIZE)*.5                                                 00003180
    YS=XFAR-YS                                                            00003190
    CALL CENT(XNAME,NTT)                                                  00003200
    NLT=-NTT                                                              00003210
    CALL EXIS(YS,XSTP,XNAME,NLT,XAXIS,90.,XMIN,DX)                        00003220
```

```
      JB=1                                                                  00003230
      DO 260 JA=1,K                                                         00003240
      JB=JB+1                                                               00003250
      IF(JB.EQ.8) JB=2                                                      00003260
      YST=XSTP-.5*FLOAT(JA-1)                                               00003270
      CALL CENT(YNAME(1,JA),NTT)                                            00003280
      CALL EXIS(XFAR,YST,YNAME(1,JA),NTT,YSIZE,180.,YMIN(JA),DY(JA))        00003290
      DO 230 JC=1,N                                                         00003300
  230 Y(JC,JA)=XFAR-Y(JC,JA)                                                00003310
      JC=NPT                                                                00003320
      IF(NPA.EQ.10) JC=JB*NSIGN                                             00003330
      CALL LINE(Y(1,JA),X,N,1,JC)                                           00003340
      DO 260 JC=1,N                                                         00003350
      Y(JC,JA)=XFAR-Y(JC,JA)                                                00003360
  260 CONTINUE                                                              00003370
      XL=XFAR+.8                                                            00003380
      CALL CENT(TITLE,NTT)                                                  00003390
      YL=XSIZE*.5+1.-FLOAT(NTT/2)*.12                                       00003400
      CALL SYMBOL(XL,YL,.14,TITLE,90.,NTT)                                  00003410
      YAX=XSIZE+3.                                                          00003420
  300 CALL PLOT(0.,YAX,-3)                                                  00003430
      CALL SYMBOL(0.,0.,.21,'BOX 81  WINFREY',0.,15)                        00003440
      CALL PLOT(1.25,4.,-3)                                                 00003450
      CALL PLOTE                                                            00003460
      WRITE(6,380)(TITLE(J),J=1,20)                                         00003470
  380 FORMAT(/////20X,75HA PLOT HAS BEEN DRAWN BY SUBROUTINE DRUA CONTAI00003480
     1NING THE FOLLOWING TITLE -      ,////20X,20A4,////)                  00003490
C   RESTORE ORIGINAL VALUES TO X AND Y                                      00003500
      DO 390 JA=1,N                                                         00003510
      X(JA)=(X(JA)-XSTP)*DX+XMIN                                            00003520
      DO 390 JB=1,K                                                         00003530
  390 Y(JA,JB)=Y(JA,JB)*DY(JB)+YMIN(JB)                                     00003540
      RETURN                                                                00003550
  400 JA=2+K                                                                00003560
      WRITE(6,450) JA                                                       00003570
  450 FORMAT(1H1////20X,43HNOT ENOUGH DATA CARDS FOR SUBROUTINE DRUA.       00003580
     1  ////I22,52H CARDS ARE READ EACH TIME SUBROUTINE DRUA IS CALLED.     00003590
     2    ////20X54HRETURNED TO CALLING ROUTINE WITHOUT STARTING A PLOT.00003600
     3    /1H1//)                                                          00003610
      RETURN                                                                00003620
      END                                                                   00003630

      SUBROUTINE DRUB(X,Y,K,N,XSIZE,YSIZE,NPT,LABEL,TITLE,XNAME,YNAME)      00003640
      DIMENSION X(1),Y(N,1),YMIN(20),DY(20)                                 00003650
      DIMENSION TITLE(1),XNAME(1),YNAME(20,1),LABEL(1)                      00003660
      PAPER=11.                                                             00003670
      CALL PLOTS                                                            00003680
```

```
      CALL PLOT(-11.,0.,-3)                                                    00003690
      CALL SYMBOL(0.,0.,.14,LABEL,0.,80)                                       00003700
      CALL PLOT(0.,4.,-3)                                                      00003710
      NSIGN=1                                                                  00003720
      IF(NPT.LT.0) NSIGN=-1                                                    00003730
      NPA=NPT*NSIGN                                                            00003740
      XST=FLOAT(K)*.5                                                          00003750
      XSTP=XST+(PAPER-XSIZE)*.5                                                00003760
      IF(XSIZE.GT.8.01) XSTP=XST+1.                                            00003770
      XAXIS=XSIZE-XST                                                          00003780
      CALL SCALE(X,N,1,XAXIS,0.,XMIN,DX)                                       00003790
      DO 100 JA=1,K                                                            00003800
      CALL SCALE(Y(1,JA),N,1,YSIZE,0.,YMIN(JA),DY(JA))                         00003810
  100 CONTINUE                                                                 00003820
      DO 130 JA=1,N                                                            00003830
  130 X(JA)=X(JA)+XSTP                                                         00003840
      YMAX=YMIN(1)+DY(1)*YSIZE                                                 00003850
      YS=ABS(YMIN(1))/DY(1)                                                    00003860
      IF(YMAX.LT.0.) YS=0.                                                     00003870
      IF(YMIN(1). GT.0.) YS=0.                                                 00003880
      IF(XSIZE.GT.8.01) GO TO 200                                              00003890
      CALL CENT(XNAME,NTT)                                                     00003900
      NLT=-NTT                                                                 00003910
      CALL EXIS(XSTP,YS,XNAME,NLT,XAXIS,0.,XMIN,DX)                            00003920
      JB=1                                                                     00003930
      DO 160 JA=1,K                                                            00003940
      JB=JB+1                                                                  00003950
      IF(JB.EQ.8) JB=2                                                         00003960
      YST=XSTP-.50*FLOAT(JA-1)                                                 00003970
      CALL CENT(YNAME(1,JA),NTT)                                               00003980
      CALL EXIS(YST,0.,YNAME(1,JA),NTT,YSIZE,90.,YMIN(JA),DY(JA))              00003990
      JC=NPT                                                                   00004000
      IF(NPA.EQ.10) JC=JB*NSIGN                                                00004010
      CALL LINE(X,Y(1,JA),N,1,JC)                                              00004020
  160 CONTINUE                                                                 00004030
      YL=7.8                                                                   00004040
      CALL CENT(TITLE,NTT)                                                     00004050
      XL=PAPER*.5-FLOAT(NTT/2)*.12                                             00004060
      CALL SYMBOL(XL,  YL,.14,TITLE,0.,NTT)                                    00004070
      YAX=YSIZE+3.                                                             00004080
      GO TO 300                                                                00004090
  200 XFAR=(PAPER+YSIZE)*.5                                                    00004100
      YS=XFAR-YS                                                               00004110
      CALL CENT(XNAME,NTT)                                                     00004120
      NLT=-NTT                                                                 00004130
      CALL EXIS(YS,XSTP,XNAME,NLT,XAXIS,90.,XMIN,DX)                           00004140
      JB=1                                                                     00004150
      DO 260 JA=1,K                                                            00004160
```

```
      JB=JB+1                                                                  00004170
      IF(JB.EQ.8) JB=2                                                         00004180
      YST=XSTP-.50*FLOAT(JA-1)                                                 00004190
      CALL CENT(YNAME(1,JA),NTT)                                               00004200
      CALL EXIS(XFAR,YST,YNAME(1,JA),NTT,YSIZE,180.,YMIN(JA),DY(JA))           00004210
      DO 230 JC=1,N                                                            00004220
  230 Y(JC,JA)=XFAR-Y(JC,JA)                                                   00004230
      JC=NPT                                                                   00004240
      IF(NPA.EQ.10) JC=JB*NSIGN                                                00004250
      CALL LINE(Y(1,JA),X,N,1,JC)                                              00004260
      DO 260 JC=1,N                                                            00004270
      Y(JC,JA)=XFAR-Y(JC,JA)                                                   00004230
  260 CONTINUE                                                                 00004290
      XL=XFAR+.8                                                               00004300
      IF(YS.LT..01) XL=XL+.55                                                  00004310
      CALL CENT(TITLE,NTT)                                                     00004320
      YL=XSIZE*.5+1.-FLOAT(NTT/2)*.12                                          00004330
      CALL SYMBOL(XL,YL,.14,TITLE,90.,NTT)                                     00004340
      YAX=XSIZE+3.                                                             00004350
  300 CALL PLOT(0.,YAX,-3)                                                     00004360
      CALL SYMBOL(0.,0.,.14,LABEL,0.,80)                                       00004370
      CALL PLOT(1.25,4.,-3)                                                    00004380
      CALL PLOTE                                                               00004390
      WRITE(6,400)(TITLE(J),J=1,20)                                            00004400
  400 FORMAT(/////20X,75HA PLOT HAS BEEN DRAWN BY SUBROUTINE DRUB CONTAI       00004410
     1NING THE FOLLOWING TITLE -      ,////20X,20A4,////)                      00004420
C   RESTORE ORIGINAL VALUES OF X AND Y                                         00004430
      DO 420 JA=1,N                                                            00004440
      X(JA)=(X(JA)-XSTP)*DX+XMIN                                               00004450
      DO 420 JB=1,K                                                            00004460
  420 Y(JA,JB)=Y(JA,JB)*DY(JB)+YMIN(JB)                                        00004470
      RETURN                                                                   00004480
      END                                                                      00004490


      SUBROUTINE DRUC(X,Y,K,N,XSIZE,YSIZE,NPT,LABEL,TITLE,XNAME,YNAME)         00004500
      DIMENSION TITLE(1),XNAME(1),YNAME(1),LABEL(1),X(N,1),Y(N,1)              00004510
      PAPER=11.                                                                00004520
      CALL PLOTS                                                               00004530
      CALL PLOT(-11.,0.,-3)                                                    00004540
      CALL SYMBOL(0.,0.,.14,LABEL,0.,80)                                       00004550
      CALL PLOT(0.,4.,-3)                                                      00004560
      NSIGN=1                                                                  00004570
      IF(NPT.LT.0) NSIGN=-1                                                    00004580
      NPA=NPT*NSIGN                                                            00004590
      XST=1.                                                                   00004600
      XSTP=XST+(PAPER-XSIZE)*.5                                                00004610
      IF(XSIZE.GT.8.01) XSTP=XST+1.                                            00004620
```

```
      XAXIS=XSIZE-XST                                                    00004630
      NK=N*K                                                             00004640
      CALL SCALE(X,NK,1,XAXIS,0.,XMIN,DX)                                00004650
      CALL SCALE(Y,NK,1,YSIZE,0.,YMIN,DY)                                00004660
      DO 130 JB=1,K                                                      00004670
      DO 130 JA=1,N                                                      00004680
  130 X(JA,JB)=X(JA,JB)+XSTP                                             00004690
      YMAX=YMIN+DY*YSIZE                                                 00004700
      YS=ABS(YMIN/DY)                                                    00004710
      IF(YMAX.LT.0.) YS=0.                                               00004720
      IF(YMIN.GT.0.) YS=0.                                               00004730
      IF(XSIZE.GT.8.01) GO TO 200                                        00004740
      CALL CENT(XNAME,NTT)                                               00004750
      NLT=-NTT                                                           00004760
      CALL EXIS(XSTP,YS,XNAME,NLT,XAXIS,0.,XMIN,DX)                      00004770
      CALL CENT(YNAME,NTT)                                               00004780
      CALL EXIS(XSTP,0.,YNAME,NTT,YSIZE,90.,YMIN,DY)                     00004790
      JB=1                                                               00004800
      DO 160 JA=1,K                                                      00004810
      JB=JB+1                                                            00004820
      IF(JB.EQ.8) JB=2                                                   00004830
      JC=NPT                                                             00004840
      IF(NPA.EQ.10) JC=JB*NSIGN                                          00004850
      CALL LINE(X(1,JA),Y(1,JA),N,1,JC)                                  00004860
  160 CONTINUE                                                           00004870
      YL=-.8                                                             00004880
      CALL CENT(TITLE,NTT)                                               00004890
      XL=PAPER*.5-FLOAT(NTT/2)*.12                                       00004900
      CALL SYMBOL(XL,  YL,.14,TITLE,0.,NTT)                              00004910
      YAX=YSIZE+3.                                                       00004920
      GO TO 300                                                          00004930
  200 XFAR=(PAPER+YSIZE)*.5                                              00004940
      YS=XFAR-YS                                                         00004950
      CALL CENT(XNAME,NTT)                                               00004960
      NLT=-NTT                                                           00004970
      CALL EXIS(YS,XSTP,XNAME,NLT,XAXIS,90.,XMIN,DX)                     00004980
      CALL CENT(YNAME,NTT)                                               00004990
      CALL EXIS(XFAR,XSTP,YNAME,     NTT,YSIZE,180.,YMIN,DY)             00005000
      JB=1                                                               00005010
      DO 260 JA=1,K                                                      00005020
      JB=JB+1                                                            00005030
      IF(JB.EQ.8) JB=2                                                   00005040
      DO 230 JC=1,N                                                      00005050
  230 Y(JC,JA)=XFAR-Y(JC,JA)                                             00005060
      JC=NPT                                                             00005070
      IF(NPA.EQ.10) JC=JB*NSIGN                                          00005080
      CALL LINE(Y(1,JA),X(1,JA),N,1,JC)                                  00005090
      DO 260 JC=1,N                                                      00005100
```

```
      Y(JC,JA)=XFAR-Y(JC,JA)                                                    00005110
  260 CONTINUE                                                                  00005120
      XL=XFAR+.8                                                                00005130
      CALL CENT(TITLE,NTT)                                                      00005140
      YL=XSIZE*.5+1.-FLOAT(NTT/2)*.12                                           00005150
      CALL SYMBOL(XL,YL,.14,TITLE,90.,NTT)                                      00005160
      YAX=XSIZE+3.                                                              00005170
  300 CALL PLOT(0.,YAX,-3)                                                      00005180
      CALL SYMBOL(0.,0.,.14,LABEL,0.,80)                                        00005190
      CALL PLOT(1.25,4.,-3)                                                     00005200
      CALL PLOTE                                                                00005210
      WRITE(6,400)(TITLE(J),J=1,20)                                             00005220
  400 FORMAT(/////20X,75HA PLOT HAS BEEN DRAWN BY SUBROUTINE DRUC CONTAI00005230
     1NING THE FOLLOWING TITLE -      ,////20X,20A4,////)                       00005240
C   RESTORE ORIGINAL VALUES TO X AND Y                                          00005250
      DO 420 JA=1,N                                                             00005260
      DO 420 JB=1,K                                                             00005270
      X(JA,JB)=(X(JA,JB)-XSTP)*DX+XMIN                                          00005280
  420 Y(JA,JB)=Y(JA,JB)*DY+YMIN                                                 00005290
      RETURN                                                                    00005300
      END                                                                       00005310


      SUBROUTINE EXIS (X,Y,BCD,NC,SIZE,THETA,YMIN,DY)                           00005320
      DIMENSION BCD(1)                                                          00005330
      DATA EPS/1.E-6/                                                           00005340
      ZING=1.                                                                   00005350
      IF(NC) 1,2,2                                                              00005360
    1 ZING = -1.                                                                00005370
    2 NAC=IABS(NC)                                                              00005380
      TH=THETA*.0174533                                                         00005390
      N=SIZE+.5                                                                 00005400
      CTH=COS(TH)                                                               00005410
      STH=SIN(TH)                                                               00005420
      TN=N                                                                      00005430
      XB=X                                                                      00005440
      YB=Y                                                                      00005450
      XA=X-.1*ZING*STH                                                          00005460
      YA=Y+.1*ZING*CTH                                                          00005470
      CALL PLOT(XA,YA,3)                                                        00005480
      DO 20 I=1,N                                                               00005490
      CALL PLOT(XB,YB,2)                                                        00005500
      XC=XB+CTH                                                                 00005510
      YC=YB+STH                                                                 00005520
      CALL PLOT(XC,YC,2)                                                        00005530
      XA=XA+CTH                                                                 00005540
      YA=YA+STH                                                                 00005550
      CALL PLOT(XA,YA,2)                                                        00005560
```

```
      XB=XC                                                                    00005570
   20 YB=YC                                                                    00005580
      IF(DY) 22,31,22                                                          00005590
   22 CHAR=ABS(YMIN)                                                           00005600
      ABSV=ABS(YMIN+DY)                                                        00005610
      IF(ABSV-CHAR) 5,6,6                                                      00005620
    5 ABSV=CHAR                                                               00005630
    6 POW=0.                                                                  00005640
      CALL ANN(ABSV,BBSV,KPOW)                                                 00005650
      POW=KPOW                                                                 00005660
   93 ADY=DY*10.**(-POW)                                                       00005670
      ABSV=YMIN*10.**(-POW)+TN*ADY                                             00005680
      XA=XB-(.2*ZING-.05)*STH-.0857*CTH                                        00005690
      YA=YB+(.2*ZING-.05)*CTH-.0857*STH                                        00005700
      N=N+1                                                                    00005710
      DO 30 I=1,N                                                              00005720
      IF(ABS(ABSV)-EPS) 101,101,100                                            00005730
  100 CALL NUMBER(XA,YA,.1,ABSV,THETA,2)                                       00005740
  101 ABSV=ABSV-ADY                                                            00005750
      XA=XA-CTH                                                                00005760
   30 YA=YA-STH                                                                00005770
   31 TNC=NAC+7                                                                00005780
      XA=X+(SIZE*.5-.03*TNC)*CTH-(-.07+ZING*.36)*STH                           00005790
      YA=Y+(SIZE*.5-.03*TNC)*STH+(-.07+ZING*.36)*CTH                           00005800
      CALL SYMBOL(XA,YA,.07,BCD,THETA,NAC)                                     00005810
      XA=XA+((TNC-6.)*.06)*CTH                                                 00005820
      YA=YA+((TNC-6.)*.06)*STH                                                 00005830
  802 IF(DY) 801,50,801                                                        00005840
  801 IF(POW) 35,50,35                                                         00005850
   35 CALL SYMBOL(XA,YA,.07,7H(X10   ),THETA,7)                                00005860
      XA=XA+.24*CTH-.07*STH                                                    00005870
      YA=YA+.24*STH+.07*CTH                                                    00005880
      IF(POW) 40,50,40                                                         00005890
   40 CALL NUMBER(XA,YA,.1,POW,THETA,-1)                                       00005900
   50 RETURN                                                                   00005910
      END                                                                      00005920

      SUBROUTINE DRUQ(X,Y,K,N,XSIZE,YSIZE,NPT,LABEL,TITLE,XNAME,YNAME)         00005930
      DIMENSION TITLE(1),XNAME(1),YNAME(1),LABEL(1),X(N,1),Y(N,1)              00005940
      CALL      DRUCL(X,Y,K,N,XSIZE,YSIZE,NPT,LABEL,TITLE,XNAME,YNAME)         00005950
      RETURN                                                                   00005960
      END                                                                      00005970
```

```
      SUBROUTINE DRUCL(X,Y,K,N,XSIZE,YSIZE,NPT,LABEL,TITLE,XNAME,YNAME) 00005980
      DIMENSION TITLE(1),XNAME(1),YNAME(1),LABEL(1),X(N,1),Y(N,1)       00005990
      PAPER=11.                                                         00006000
      CALL PLOTS                                                        00006010
      CALL PLOT(-11.,0.,-3)                                             00006020
      CALL SYMBOL(0.,0.,.14,LABEL,0.,80)                                00006030
      CALL PLOT(0.,4.,-3)                                               00006040
      NSIGN=1                                                           00006050
      IF(NPT.LT.0) NSIGN=-1                                             00006060
      NPA=NPT*NSIGN                                                     00006070
      XST=1.                                                            00006080
      XSTP=XST+(PAPER-XSIZE)*.5                                         00006090
      IF(XSIZE.GT.8.01) XSTP=XST+1.                                     00006100
      XAXIS=XSIZE-XST                                                   00006110
      NK=N*K                                                            00006120
      CALL SCALE(X,NK,1,XAXIS,0.,XMIN,DX)                               00006130
      CALL SCALE(Y,NK,1,YSIZE,0.,YMIN,DY)                               00006140
      DO 130 JB=1,K                                                     00006150
      DO 130 JA=1,N                                                     00006160
  130 X(JA,JB)=X(JA,JB)+XSTP                                            00006170
      YMAX=YMIN+DY*YSIZE                                                00006180
      YS=ABS(YMIN/DY)                                                   00006190
      IF(YMAX.LT.0.) YS=0.                                              00006200
      IF(YMIN.GT.0.) YS=0.                                              00006210
      IF(XSIZE.GT.8.01) GO TO 200                                       00006220
      CALL CENT(XNAME,NTT)                                              00006230
      NLT=-NTT                                                          00006240
      CALL EXISA(XSTP,YS,XNAME,NLT,XAXIS,0.,XMIN,DX)                    00006250
      CALL CENT(YNAME,NTT)                                              00006260
      CALL EXISA(XSTP,0.,YNAME,NTT,YSIZE,90.,YMIN,DY)                   00006270
      JB=1                                                              00006280
      DO 160 JA=1,K                                                     00006290
      JB=JB+1                                                           00006300
      IF(JB.EQ.8) JB=2                                                  00006310
      JC=NPT                                                            00006320
      IF(NPA.EQ.10) JC=JB*NSIGN                                         00006330
      CALL LIND(X(1,JA),Y(1,JA),N,1,JC)                                 00006340
      CALL LIND(X(1,JA),Y(1,JA),N,1,JC)                                 00006350
      CALL LIND(X(1,JA),Y(1,JA),N,1,JC)                                 00006360
  160 CONTINUE                                                          00006370
      YL=-.8                                                            00006380
      CALL CENT(TITLE,NTT)                                              00006390
      XL=PAPER*.5-FLOAT(NTT/2)*.18                                      00006400
      CALL SYMBOL(XL,  YL,.21,TITLE,0.,NTT)                             00006410
      YAX=YSIZE+3.                                                      00006420
      GO TO 300                                                         00006430
  200 XFAR=(PAPER+YSIZE)*.5                                             00006440
      YS=XFAR-YS                                                        00006450
```

```
      CALL CENT(XNAME,NTT)                                                    00006460
      NLT=-NTT                                                                00006470
      CALL EXISA(YS,XSTP,XNAME,NLT,XAXIS,90.,XMIN,DX)                         00006480
      CALL CENT(YNAME,NTT)                                                    00006490
      CALL EXISA(XFAR,XSTP,YNAME,     NTT,YSIZE,180.,YMIN,DY)                 00006500
      JB=1                                                                    00006510
      DO 260 JA=1,K                                                           00006520
      JB=JB+1                                                                 00006530
      IF(JB.EQ.8) JB=2                                                        00006540
      DO 230 JC=1,N                                                           00006550
  230 Y(JC,JA)=XFAR-Y(JC,JA)                                                  00006560
      JC=NPT                                                                  00006570
      IF(NPA.EQ.10) JC=JB*NSIGN                                               00006580
      CALL LIND(Y(1,JA),X(1,JA),N,1,JC)                                       00006590
      CALL LIND(Y(1,JA),X(1,JA),N,1,JC)                                       00006600
      CALL LIND(Y(1,JA),X(1,JA),N,1,JC)                                       00006610
      DO 260 JC=1,N                                                           00006620
      Y(JC,JA)=XFAR-Y(JC,JA)                                                  00006630
  260 CONTINUE                                                                00006640
      XL=XFAR+.8                                                              00006650
      CALL CENT(TITLE,NTT)                                                    00006660
      YL=XSIZE*.5+1.-FLOAT(NTT/2)*.18                                         00006670
      CALL SYMBOL(XL,YL,.21,TITLE,90.,NTT)                                    00006680
      YAX=XSIZE+3.                                                            00006690
  300 CALL PLOT(0.,YAX,-3)                                                    00006700
      CALL SYMBOL(0.,0.,.14,LABEL,0.,80)                                      00006710
      CALL PLOT(1.25,4.,-3)                                                   00006720
      CALL PLOTE                                                              00006730
      WRITE(6,400)(TITLE(J),J=1,20)                                           00006740
  400 FORMAT(/////20X,75HA PLOT HAS BEEN DRAWN BY SUBROUTINE DRUQ CONTAI      00006750
     1NING THE FOLLOWING TITLE -      ,////20X,20A4,////)                     00006760
C   RESTORE ORIGINAL VALUES TO X AND Y                                        00006770
      DO 420 JA=1,N                                                           00006780
      DO 420 JB=1,K                                                           00006790
      X(JA,JB)=(X(JA,JB)-XSTP)*DX+XMIN                                        00006800
  420 Y(JA,JB)=Y(JA,JB)*DY+YMIN                                               00006810
      RETURN                                                                  00006820
      END                                                                     00006830
```

```
      SUBROUTINE DTPRIM( RECENT, KK, OLD, DT, DTP, NPRINT)                  00000010
C                                                                           00000020
      IMPLICIT REAL*8(A-H,O-Z)                                              00000030
C                                                                           00000040
      INTEGER YES                                                           00000050
C                                                                           00000060
      DIMENSION DTP(1)                                                      00000070
C                                                                           00000080
      COMMON NUNIT, IPRINT                                                  00000090
C                                                                           00000100
      DATA YES/4HYES /, NO/4HNO  /                                          00000110
C                                                                           00000120
 5001 FORMAT(' ', 10X, 'FOR INTERATION ', I1, ' RECENT = ',                 00000130
     1       1PD15.7, ' AND OLD = ', D15.7, '   OLD - RECENT =', D15.7)     00000140
C                                                                           00000150
      SMALL = 1.0D-10                                                       00000160
C                                                                           00000170
C                                                                           00000180
      DIFF = OLD - RECENT                                                   00000190
      IF(DIFF .LT. SMALL)  DIFF = SMALL                                     00000200
C                                                                           00000210
      DTP(KK) = ( OLD/ DIFF) * DT                                           00000220
C                                                                           00000230
      IF(NPRINT .EQ. NO)  RETURN                                            00000240
C                                                                           00000250
      WRITE(NUNIT,5001) KK, RECENT, OLD, DIFF                               00000260
C                                                                           00000270
      RETURN                                                                00000280
      END                                                                   00000290
```

```
C                                                                       00000010
C-----------------------------------------------------------------------00000020
C                                                                       00000030
C                  SUBROUTINE CODED BY DR. R. C. WINFREY                00000040
C                                                                       00000050
C-----------------------------------------------------------------------00000060
C                                                                       00000070

      SUBROUTINE DVVS(A,B,ELAM,X,N,NA,NB,NX,KSYS,NERR)                  00000080
C                                                                       00000090
C     THIS ROUTINE FINDS THE EIGENVALUES AND ON OPTION THE              00000100
C          EIGENVECTORS OF THE SYSTEM (A-ELAM*B)X=0                     00000110
C                                                                       00000120
C     A=        SYMMETRIC MATRIX--DESTROYED BY ROUTINE                  00000130
C     B=        POSITIVE DEFINITE MATRIX--DESTROYED BY ROUTINE          00000140
C     ELAM=     VECTOR WHERE EIGENVALUES WILL BE STORED                 00000150
C     X=        MATRIX WHERE EIGENVECTORS WILL BE STORED BY COLUMNS     00000160
C     N=        ORDER OF MATRICES A, B AND X AND VECTOR ELAM            00000170
C     NA=       ROW DIMENSION OF MATRIX A(GT OR =N)                     00000180
C     NB=       ROW DIMENSION OF MATRIX B(GT OR =N)--IF B IS IDENTITY   00000190
C                SET NB=0, THEN STORAGE FOR B IS NOT NECESSARY          00000200
C     NX=       ROW DIMENSION OF MATRIX X(GT OR =N)--IF VECTORS ARE NOT  00000210
C                DESIRED SET NX=0, THEN STORAGE FOR X IS NOT NECESSARY  00000220
C     NERR=    RETURN INDICATOR                                         00000230
C                =0, NORMAL RETURN                                      00000240
C                =NEGATIVE, SOLUTION DID NOT CONVERGE                   00000250
C                =POSITVE, B IS NOT POSITIVE DEFINITE AND NERR CONTAINS 00000260
C                 THE INDEX OF DIAGONAL ELEMENT CAUSING THIS CONDITION  00000270
C                                                                       00000280
      DOUBLE PRECISION A(KSYS,1),B(KSYS,1),X(KSYS,KSYS),ELAM(KSYS)      00000290
      DOUBLE PRECISION TBI,T1,T2,T3,TL1,TAI,TBJ,TLJ,S,C,TLI,EMAX        00000300
      TL1=0.                                                            00000310
      NN=N                                                              00000320
      NERR=0                                                            00000330
      NNX=NX                                                            00000340
C                                                                       00000350
CC    IF EIGENVECTORS ARE REQUESTED STORE IDENTITY AT X                 00000360
C                                                                       00000370
      IF (NNX.EQ.0)GO TO 20                                             00000380
      DO 15 I=1,NN                                                      00000390
      DO 10 J=1,NN                                                      00000400
   10 X(I,J)=0.0                                                        00000410
   15 X(I,I)=1.0                                                        00000420
C                                                                       00000430
CC    IF B=I MATRIX REDUCTION NOT NECESSARY                             00000440
C                                                                       00000450
   20 IF (NB.EQ.0)GO TO 200                                             00000460
```

```
C                                                                       00000470
C       MATRIX REDUCTION---FIND MATRIX M SUCH THAT M(T)BM=I             00000480
C            THE ACTUAL COMPUTATION OF M(UPPER TRIANGULAR) IS ONLY      00000490
C            DONE WHEN EIGENVECTORS ARE REQUESTED IT IS STORED AT X     00000500
C       REDUCE B TO I(UPPER TRIANGULAR)                                 00000510
C       REDUCE A TO A1=M(T)AM(LOWER TRIANGULAR)                         00000520
C       THE EIGENVALUES OF (A-ELAM*B)X=0 EQUAL THOSE OF (A1-ELAM*I)Y=0  00000530
C       THE EIGENVECTORS HAVE THE RELATION X=YM                         00000540
C                                                                       00000550
      DO 150 I=1,NN                                                     00000560
      TBI=B(I,I)                                                        00000570
      IF(TBI.GT.0.0) GO TO 100                                          00000580
      NERR=I                                                            00000590
      RETURN                                                            00000600
  100 T1=1.0/TBI                                                        00000610
      TLI=DSQRT(T1)                                                     00000620
      TAI=A(I,I)                                                        00000630
      IM1=I-1                                                           00000640
      IF(I.EQ.NN) GO TO 130                                             00000650
      IP1=I+1                                                           00000660
      DO 125 J=IP1,NN                                                   00000670
      TBJ=B(I,J)                                                        00000680
      ELAM(J)=-TBJ*T1                                                   00000690
      TLJ=ELAM(J)                                                       00000700
      IF(IM1.EQ.0) GO TO 110                                            00000710
      DO 105 K=1,IM1                                                    00000720
  105 A(J,K)=TLJ*A(I,K)+A(J,K)                                          00000730
  110 T2=TLJ*TAI+A(J,I)                                                 00000740
      DO 115 K=IP1,J                                                    00000750
      B(K,J)=B(K,J)+ELAM(K)*TBJ                                         00000760
  115 A(J,K)=ELAM(K)*T2+TLJ*A(K,I)+A(J,K)                               00000770
      IF (NNX.EQ.0)GO TO 125                                            00000780
C                                                                       00000790
C       IF NO VECTORS ARE REQUIRED M IS NOT COMPUTED                    00000800
C                                                                       00000810
      DO 120 K=1,I                                                      00000820
  120 X(K,J)=X(K,I)*TLJ+X(K,J)                                          00000830
  125 CONTINUE                                                          00000840
      DO 127 J=IP1,NN                                                   00000850
  127 A(J,I)=TLI*(ELAM(J)*TAI+A(J,I))                                   00000860
      IF(IM1.EQ.0) GO TO 140                                            00000870
  130 DO 135 K=1,IM1                                                    00000880
  135 A(I,K)=TLI*A(I,K)                                                 00000890
  140 IF (NNX.EQ.0)GO TO 150                                            00000900
      DO 145 K=1,I                                                      00000910
  145 X(K,I)=X(K,I)*TLI                                                 00000920
  150 A(I,I)=T1*TAI                                                     00000930
C                                                                       00000940
```

```
C      SEQUENTIAL THRESHOLD JACOBI METHOD                                00000950
C                                                                        00000960
  200  NM1=NN-1                                                          00000970
C                                                                        00000980
C      INITIALIZE THRESHOLD--FIND MAXIMUM OFF DIAGONAL ELEMENT           00000990
C                                                                        00001000
       IS=6                                                              00001010
       EMAX=0.0                                                          00001020
       DO 215 J=1,NM1                                                    00001030
       JP1=J+1                                                           00001040
       DO 215 I=JP1,NN                                                   00001050
       T1=DABS(A(I,J))                                                   00001060
       IF(T1.GT.EMAX) EMAX=T1                                            00001070
  215  CONTINUE                                                          00001080
       EMAX=EMAX/4.0                                                     00001090
C                                                                        00001100
C      DIAGONALIZATION SWEEP                                             00001110
C                                                                        00001120
  300  IST=0                                                             00001130
       DO 350 J=1,NM1                                                    00001140
       JP1=J+1                                                           00001150
       DO 350 I=JP1,NN                                                   00001160
       T1=A(I,J)                                                         00001170
       IF(DABS(T1).LE.EMAX)GO TO 350                                     00001180
       IST=IST+1                                                         00001190
C                                                                        00001200
C      FORM ROTATION MATRIX ELEMENTS C AND S                             00001210
C                                                                        00001220
       T2=A(J,J)-A(I,I)                                                  00001230
       IF(T2.EQ.0.0)GO TO 310                                            00001240
       T2=2.0*(T1/T2)                                                    00001250
       IF(DABS(T2).GE.1.D9)GO TO 310                                     00001260
       T2=T2/(1.0+DSQRT(1.D0+T2*T2))                                     00001270
       C=1.0/DSQRT(1.D0+T2*T2)                                           00001280
       S=C*T2                                                            00001290
       GO TO 320                                                         00001300
  310  C=1./DSQRT(2.D0)                                                  00001310
       IF(T1.LE.0.0)GO TO 315                                            00001320
       S=C                                                               00001330
       GO TO 320                                                         00001340
  315  S=-C                                                              00001350
C                                                                        00001360
C      REDUCE A BY ROTATION USING COLUMNS AND ROWS I AND J               00001370
C                                                                        00001380
  320  IM1=I-1                                                           00001390
       T3=C*A(I,J)-S*A(J,J)                                              00001400
       A(J,J)=C*A(J,J)+S*A(I,J)                                          00001410
       IF(I.EQ.JP1) GO TO 327                                            00001420
```

```
      DO 325 K=JP1,IM1                                                  00001430
      T1=A(K,J)                                                         00001440
      T2=A(I,K)                                                         00001450
      A(K,J)=C*T1+S*T2                                                  00001460
  325 A(I,K)=C*T2-S*T1                                                  00001470
  327 DO 330 K=I,NN                                                     00001480
      T1=A(K,J)                                                         00001490
      T2=A(K,I)                                                         00001500
      A(K,J)=C*T1+S*T2                                                  00001510
  330 A(K,I)=-S*T1+C*T2                                                 00001520
      DO 335 K=1,J                                                      00001530
      T1=A(J,K)                                                         00001540
      T2=A(I,K)                                                         00001550
      A(J,K)=C*T1+S*T2                                                  00001560
  335 A(I,K)=-S*T1+C*T2                                                 00001570
      A(I,I)=-S*T3+C*A(I,I)                                             00001580
C                                                                       00001590
C     FORM EIGENVECTORS IF REQUESTED                                    00001600
C                                                                       00001610
      IF (NNX.EQ.0)GO TO 350                                            00001620
      DO 345 K=1,NN                                                     00001630
      T1=X(K,J)                                                         00001640
      T2=X(K,I)                                                         00001650
      X(K,J)=C*T1+S*T2                                                  00001660
  345 X(K,I)=-S*T1+C*T2                                                 00001670
  350 CONTINUE                                                          00001680
C                                                                       00001690
C     TEST FOR CONVERGENCE AND MODIFY THRESHOLD                         00001700
C                                                                       00001710
      IS=IS-1                                                           00001720
      IF(IS.LE.0)GO TO 400                                              00001730
      K=-(2**(5-IS))                                                    00001740
      EMAX=EMAX*(2.0**K)                                                00001750
      GO TO 300                                                         00001760
  400 IF(IST.EQ.0)GO TO 500                                             00001770
      IF(IS.GE.(-33))GO TO 300                                          00001780
C                                                                       00001790
C     METHOD HAS FAILED TO CONVERGE                                     00001800
C                                                                       00001810
      NERR=-1                                                           00001820
C                                                                       00001830
C     TRANSFER EIGENVALUES AND EXIT                                     00001840
C                                                                       00001850
  500 DO 510 I=1,NN                                                     00001860
  510 ELAM(I)=A(I,I)                                                    00001870
      RETURN                                                            00001880
      END                                                               00001890
```

```
      SUBROUTINE FIXFOR(C, F)                                          00000010
C                                                                      00000020
      IMPLICIT REAL*8(A-H,O-Z)                                         00000030
C                                                                      00000040
      INTEGER C, YES                                                   00000050
C                                                                      00000060
      DIMENSION F(1)                                                   00000070
C                                                                      00000080
      COMMON NUNIT, IPRINT                                             00000090
C                                                                      00000100
      DATA  YES/4HYES /, NO/4HNO  /                                    00000110
C                                                                      00000120
C                                                                      00000130
      GO TO (10, 20, 30, 40, 50, 60, 70, 80), C                        00000140
C                                                                      00000150
   10 CONTINUE                                                         00000160
      F(1) = 0.0D0                                                     00000170
      F(2) = 0.0D0                                                     00000180
      F(7) = 0.0D0                                                     00000190
      F(8) = -F(2)                                                     00000200
      RETURN                                                           00000210
C                                                                      00000220
   20 CONTINUE                                                         00000230
      F(1) = 0.0D0                                                     00000240
      F(2) = 0.0D0                                                     00000250
      RETURN                                                           00000260
C                                                                      00000270
   30 CONTINUE                                                         00000280
      F(1) = 0.0D0                                                     00000290
      F(7) = 0.0D0                                                     00000300
      F(8) = -F(2)                                                     00000310
      RETURN                                                           00000320
C                                                                      00000330
   40 CONTINUE                                                         00000340
      F(1) = 0.0D0                                                     00000350
      F(8) = -F(2)                                                     00000360
      RETURN                                                           00000370
C                                                                      00000380
   50 CONTINUE                                                         00000390
      F(7) = 0.0D0                                                     00000400
      F(2) = 0.0D0                                                     00000410
      F(8) = 0.0D0                                                     00000420
      RETURN                                                           00000430
C                                                                      00000440
   60 CONTINUE                                                         00000450
      F(2) = 0.0D0                                                     00000460
```

```
      F(8) = 0.0D0                                                      00000470
      RETURN                                                            00000480
C                                                                       00000490
   70 CONTINUE                                                          00000500
      F(7) = 0.0D0                                                      00000510
      F(8) = -F(2)                                                      00000520
      RETURN                                                            00000530
C                                                                       00000540
   80 CONTINUE                                                          00000550
      F(8) = -F(2)                                                      00000560
      RETURN                                                            00000570
      END                                                               00000580
```



```
      SUBROUTINE ADJUST(I1,I2,QR,QRD,QRDD,Q,QD,QDD)                     00000010
C                                                                       00000020
      IMPLICIT REAL*8(A-H,O-Z)                                          00000030
C                                                                       00000040
      INTEGER YES                                                       00000050
C                                                                       00000060
      DIMENSION QR(1), QRD(1), QRDD(1), Q(1), QD(1), QDD(1)             00000070
C                                                                       00000080
      COMMON NUNIT, IPRINT                                              00000090
C                                                                       00000100
      DATA  YES/4HYES /, NO/4HNO  /                                     00000110
C                                                                       00000120
      QR  (I1) = Q  (I2)                                                00000130
      QRD (I1) = QD (I2)                                                00000140
      QRDD(I1) = QDD(I2)                                                00000150
C                                                                       00000160
      RETURN                                                            00000170
      END                                                               00000180
```

```
      SUBROUTINE GPRINT(FPLOT, DEG, KTIME, YNAME, XSCALE, IP, NPRINT,    00000010
     1             GRID, LINES, TITLE, LABEL)                            00000020
C                                                                        00000030
      INTEGER*2 GRID(LINES,1)                                            00000040
C                                                                        00000050
      INTEGER YES                                                        00000060
C                                                                        00000070
      DIMENSION YNAME(20)  , FPLOT(KTIME)  , DEG(1), XSCALE(1),          00000080
     1          TITLE(1), LABEL(1)                                       00000090
C                                                                        00000100
      COMMON NUNIT, IPRINT                                               00000110
C                                                                        00000120
      DATA YES/4HYES /, NO/4HNO  /                                       00000130
C                                                                        00000140
 5000 FORMAT('0',5X,4(1PE15.7, 5X)  )                                    00000150
 5001 FORMAT(' ',5X,I5,5X,1P2E15.7)                                      00000160
 5026 FORMAT('1', 18A4)                                                  00000170
 5027 FORMAT('+',72X, 15A4)                                              00000180
 5028 FORMAT('0', 40X, 18A4)                                             00000190
      XMIN = DEG(1)                                                      00000200
      XMAX = DEG(KTIME)                                                  00000210
      YMIN =  1.0E40                                                     00000220
      YMAX=-1.E40                                                        00000230
C                                                                        00000240
      DO  10  K = 1, KTIME                                               00000250
      IF(FPLOT(K) .GT. YMAX)  YMAX = FPLOT(K)                            00000260
      IF(FPLOT(K) .LT. YMIN)  YMIN = FPLOT(K)                            00000270
   10 CONTINUE                                                           00000280
      WRITE(NUNIT,5026) (LABEL(JA), JA = 1,18)                           00000290
      WRITE(NUNIT,5027)  (TITLE(JA), JA = 1, 15)                         00000300
      WRITE(NUNIT,5028) ( YNAME(JA), JA = 1,18 )                         00000310
C                                                                        00000320
      IRYP1 = 80*IP + 1                                                  00000330
      CALL OLPLOT(DEG,FPLOT,KTIME,XMAX,XMIN,YMAX,YMIN,IRYP1,GRID,XSCALE,00000340
     1            0, NPRINT, LINES)                                      00000350
C                                                                        00000360
      IF(NPRINT .EQ. NO)  RETURN                                         00000370
C                                                                        00000380
      WRITE(6,5000) XMIN,XMAX,YMIN,YMAX                                  00000390
C                                                                        00000400
      DO  51  JA = 1, KTIME                                              00000410
      WRITE(6,5001) JA, DEG(JA), FPLOT(JA)                               00000420
   51 CONTINUE                                                           00000430
C                                                                        00000440
      RETURN                                                             00000450
      END                                                                00000460
```

```
      SUBROUTINE GRAPH(FPLOT, YNAME, XNAME, DEG1, DEG2, Y1, Y2, Y3, Y4,  00000010
     1                 YNAME1, YNAME2, PIN2$8, CLEAR,                    00000020
     2           NTIME, LABEL, TITLE, IDRAW, IPLOT, XSCALE,              00000030
     3           IP, NPRINT, GRID, LINES)                                00000040
C                                                                        00000050
      INTEGER*2 GRID(LINES,1)                                            00000060
      INTEGER YES, PIN2$8                                                00000070
C                                                                        00000080
      REAL*8 CLEAR                                                       00000090
      REAL*4 LABEL                                                       00000100
C                                                                        00000110
      DIMENSION XNAME(1), DEG1(1), DEG2(NTIME,2), XSCALE(1), TITLE(1),   00000120
     1          FPLOT(NTIME,1), YNAME(20,1), Y1(NTIME,1), Y2(NTIME,1),   00000130
     2          Y3(NTIME,1), Y4(NTIME,1),                                00000140
     3          YNAME1(20,1), YNAME2(20,1), LABEL(1)                     00000150
C                                                                        00000160
      COMMON NUNIT, IPRINT                                               00000170
C                                                                        00000180
      DATA YES/4HYES /, NO/4HNO  /                                       00000190
C                                                                        00000200
      DO  5  I = 1,10                                                    00000210
      IF(FPLOT(1,I) .EQ. 0.0)  FPLOT(1,I) = 1.0E-10                      00000220
    5 CONTINUE                                                           00000230
C                                                                        00000240
      IF(IDRAW .EQ. NO)   GO TO 2501                                     00000250
C                                                                        00000260
C                                                                        00000270
 4201 CALL DRUB (DEG1,Y1,2,NTIME,10.,6.,1,LABEL,TITLE,XNAME,YNAME1)      00000280
 4202 CALL DRUB (DEG1,Y2,2,NTIME,10.,6.,1,LABEL,TITLE,XNAME,YNAME2)      00000290
      CALL DRUC (DEG2,Y3,2,NTIME,10.,6.,1,LABEL,TITLE,XNAME,YNAME(1,12))00000300
 4203 CALL DRUPB(DEG1,FPLOT(1,5),1,NTIME,10.,6.,1,LABEL,TITLE,XNAME,     00000310
     1           YNAME(1,5) )                                            00000320
 4204 CALL DRUPB(DEG1,FPLOT(1,6),1,NTIME,10.,6.,1,LABEL,TITLE,XNAME,     00000330
     1           YNAME(1,6) )                                            00000340
 4205 CALL DRUPB(DEG1,FPLOT(1,7),1,NTIME,10.,6.,1,LABEL,TITLE,XNAME,     00000350
     1           YNAME(1,7) )                                            00000360
C                                                                        00000370
      IF(PIN2$8 .EQ. YES)  GO TO 4207                                    00000380
C                                                                        00000390
 4206 CALL DRUPB(DEG1,FPLOT(1,9),1,NTIME,10.,6.,1,LABEL,TITLE,XNAME,     00000400
     1           YNAME(1,9) )                                            00000410
C                                                                        00000420
 4207 IF(CLEAR .LE. -10.0)  GO TO 2501                                   00000430
C                                                                        00000440
 4208 CALL DRUPB(DEG1,FPLOT(1,10),1,NTIME,10.,6.,1,LABEL,TITLE,XNAME,    00000450
     1           YNAME(1,10) )                                           00000460
```

```
 4209 CALL DRUPB(DEG1,FPLOT(1,11),1,NTIME,10.,6.,1,LABEL,TITLE,XNAME,    00000470
     1       YNAME(1,11) )                                              00000480
      CALL DRUC (DEG2,Y4,2,NTIME,10.,6.,1,LABEL,TITLE,XNAME,YNAME(1,13))00000490
C                                                                       00000500
C                                                                       00000510
C                                                                       00000520
 2501 CONTINUE                                                          00000530
C                                                                       00000540
C                                                                       00000550
C                                                                       00000560
      IF(IPLOT .EQ. NO) GO TO 4199                                      00000570
C                                                                       00000580
      IF(PIN2$8 .EQ.YES)  GO TO 4102                                    00000590
 4101 CALL GPRINT(FPLOT(1, 1), DEG1, NTIME, YNAME(1, 1), XSCALE, IP,    00000600
     1             NPRINT, GRID, LINES, TITLE, LABEL)                 00000610
C                                                                       00000620
 4102 CALL GPRINT(FPLOT(1, 2), DEG1, NTIME, YNAME(1, 2), XSCALE, IP,    00000630
     1             NPRINT, GRID, LINES, TITLE, LABEL)                 00000640
 4103 CALL GPRINT(FPLOT(1, 3), DEG1, NTIME, YNAME(1, 3), XSCALE, IP,    00000650
     1             NPRINT, GRID, LINES, TITLE, LABEL)                 00000660
 4104 CALL GPRINT(FPLOT(1, 4), DEG1, NTIME, YNAME(1, 4), XSCALE, IP,    00000670
     1             NPRINT, GRID, LINES, TITLE, LABEL)                 00000680
 4105 CALL GPRINT(FPLOT(1, 5), DEG1, NTIME, YNAME(1, 5), XSCALE, IP,    00000690
     1             NPRINT, GRID, LINES, TITLE, LABEL)                 00000700
 4106 CALL GPRINT(FPLOT(1, 6), DEG1, NTIME, YNAME(1, 6), XSCALE, IP,    00000710
     1             NPRINT, GRID, LINES, TITLE, LABEL)                 00000720
C                                                                       00000730
      IF(CLEAR  .LE. -10.0)  GO TO 4200                                 00000740
 4107 CALL GPRINT(FPLOT(1, 7), DEG1, NTIME, YNAME(1, 7), XSCALE, IP,    00000750
     1             NPRINT, GRID, LINES, TITLE, LABEL)                 00000760
C                                                                       00000770
 4200 IF(PIN2$8 .EQ.YES)  GO TO 4109                                    00000780
 4108 CALL GPRINT(FPLOT(1, 8), DEG1, NTIME, YNAME(1, 8), XSCALE, IP,    00000790
     1             NPRINT, GRID, LINES, TITLE, LABEL)                 00000800
C                                                                       00000810
 4109 CALL GPRINT(FPLOT(1, 9), DEG1, NTIME, YNAME(1, 9), XSCALE, IP,    00000820
     1             NPRINT, GRID, LINES, TITLE, LABEL)                 00000830
C                                                                       00000840
      IF(CLEAR  .LE. -10.0)  GO TO 4199                                 00000850
 4110 CALL GPRINT(FPLOT(1,10), DEG1, NTIME, YNAME(1,10), XSCALE, IP,    00000860
     1             NPRINT, GRID, LINES, TITLE, LABEL)                 00000870
C                                                                       00000880
C                                                                       00000890
 4199 CONTINUE                                                          00000900
C                                                                       00000910
      RETURN                                                            00000920
      END                                                               00000930
```

```
      SUBROUTINE INITAL(KSYS,Q,QD,QDD,AMPW,FS,FZERO,XZERO,ROCKER,ISYS,   00000010
     1            COLM,COLC,COLK,DP,F,DAMP,STF,STFRI,NPRINT)             00000020
C                                                                        00000030
      IMPLICIT REAL*8(A-H,O-Z)                                           00000040
C                                                                        00000050
      INTEGER YES                                                        00000060
C                                                                        00000070
      DIMENSION COLM(KSYS), COLC(KSYS), COLK(KSYS)                       00000080
      DIMENSION Q(10), QD(1), QDD(1), DP(1), F(1), DAMP(KSYS,KSYS),      00000090
     1          STFRI(ISYS,1), STF(KSYS,KSYS)                            00000100
C                                                                        00000110
      COMMON NUNIT, IPRINT                                               00000120
C                                                                        00000130
      DATA YES/4HYES /, NO/4HNO  /                                       00000140
C                                                                        00000150
 5043 FORMAT('0', 10X, ' FROM SUBROUTINE INITAL')                        00000160
 5044 FORMAT(' ', 1P7D18.9,//  )                                         00000170
 5045 FORMAT('0',//,20X,'- - - - -  STFI - - - - - ',//)                 00000180
 5046 FORMAT('0',//,20X,'- - - -  STFRI - - - - -  ', //)                00000190
C              **********************************************            00000200
CC             **                                          **            00000210
CC             **          SET UP INITIAL VALUES           **            00000220
CC             **     OF DISPLACEMENT(Q), VELOCITY(QDD),   **            00000230
CC             **           AND ACCELERATION(QDD)          **            00000240
CC             **                                          **            00000250
CC             **********************************************            00000260
C                                                                        00000270
      DO 300 JA = 1,KSYS                                                 00000280
      QD(JA) = -AMPW                                                     00000290
      QDD(JA) = 0.0D0                                                    00000300
  300 CONTINUE                                                           00000310
C                                                                        00000320
      QD(1) = +AMPW                                                      00000330
      QD(2) = +AMPW                                                      00000340
      QD(4) = -AMPW*ROCKER                                               00000350
      QD(7) = +AMPW*ROCKER                                               00000360
      QD(8) = +AMPW                                                      00000370
C                                                                        00000380
      Q(1) = XZERO                                                       00000390
C                                                                        00000400
      DO 350 JA = 1,ISYS                                                 00000410
      DP(JA) = -(COLM(JA)*QDD(1)+COLC(JA)*QD(1)+COLK(JA)*Q(1))           00000420
C                                                                        00000430
      DO 350 JB = 1,ISYS                                                 00000440
      DP(JA) = DP(JA)-DAMP(JA,JB)*QD(JB+1)                               00000450
      STFRI(JA,JB) = STF (JA,JB)                                         00000460
```

```
C                                                                       00000470
  350 CONTINUE                                                          00000480
C                                                                       00000490
      DO  8  I = 1, KSYS                                                00000500
      F(I) = 0.0D0                                                      00000510
    8 CONTINUE                                                          00000520
C                                                                       00000530
CCC               ********************************************        00000540
CCC               **                                        **        00000550
CCC               **           CALL SUBROUTINE DINVS          **      00000560
CCC               **  DINVS CALCULATES THE INVERSE STIFFNESS  **      00000570
CCC               **                MATRIX                    **      00000580
CCC               **        SEND STF  - - RETURN STFRI        **      00000590
CCC               **                                        **        00000600
CCC               ********************************************        00000610
C                                                                       00000620
      CALL DINVS(STFRI,ISYS,ISYS)                                       00000630
C                                                                       00000640
      DO 360 JA = 1,ISYS                                                00000650
      Q(JA+1) = 0.                                                      00000660
C                                                                       00000670
      DO 360 JB = 1,ISYS                                                00000680
      Q(JA+1) = Q(JA+1)+STFRI(JA,JB)*DP(JB)                             00000690
C                                                                       00000700
  360 CONTINUE                                                          00000710
C                                                                       00000720
      CALL ADJUST(1,9, Q, QD, QDD, Q, QD, QDD)                          00000730
      CALL ADJUST(8,2, Q, QD, QDD, Q, QD, QDD)                          00000740
C                                                                       00000750
      RETURN                                                            00000760
      END                                                               00000770
```

```
      SUBROUTINE INPUT(LABEL, TITLE, XNAME, YNAME,                      00000010
     1                                AGTOUT, CARDS, TAPE, IPLOT, IDRAW, 00000020
     2           KPRINT, DAMPNG, RPM, CLEAR, WTDEG, AMP, DELT,          00000030
     3           ROCKER, AXILTH, REALTH,                                00000040
     4           NTIME, KSYS, NCLEAR, NC,                               00000050
     5           NCOUNT, IDEG, PIN2$8, MPRINT)                          00000060
C                                                                       00000070
      IMPLICIT REAL*8(A-H,O-Z)                                          00000080
C                                                                       00000090
      REAL*4 LABEL,TITLE,XNAME,YNAME,                                   00000100
     1       VLV, TWO1, TWO2                                          00000110
C                                                                       00000120
      INTEGER YES,AGTOUT,DAMPNG,TAPE,CARDS,SEAT,PIN2$8                  00000130
C                                                                       00000140
      DIMENSION YNAME(20,1), AXILTH(1), REALTH(1),                      00000150
     1          LABEL(1), TITLE(1), XNAME(1)                            00000160
C                                                                       00000170
      COMMON NUNIT, IPRINT                                              00000180
      DATA YES/4HYES /, NO/4HNO  /                                      00000190
      DATA  TWO1/'   T'/,  TWO2/'WO C'/,  VLV/'NO V'/                   00000200
C                                                                       00000210
 5001 FORMAT(18A4)                                                      00000220
 5002 FORMAT(1A4)                                                       00000230
 5003 FORMAT(D10.3)                                                     00000240
 5004 FORMAT(I4)                                                        00000250
 5005 FORMAT(1A4,2I4)                                                   00000260
 5006 FORMAT(4D10.3)                                                    00000270
 5007 FORMAT('0',10(I4,8X) )                                            00000280
 5008 FORMAT('0',6(D10.3,5X) )                                          00000290
 5009 FORMAT('0', 8(A4,10X ) )                                          00000300
 5010 FORMAT(D10.3, 2X, 1A4)                                            00000310
C                                                                       00000320
      REALTH(1) =  9.0D0                                                00000330
      REALTH(2) =  1.0D0                                                00000340
      REALTH(3) =  1.5D0                                                00000350
      REALTH(4) = 36.0D0                                                00000360
      AXILTH(1) =  1.0D0                                                00000370
      AXILTH(2) =  3.4D0                                                00000380
      AXILTH(3) =  5.1D0                                                00000390
      AXILTH(4) =  1.0D0                                                00000400
      AMP = 0.5D0                                                       00000410
      DAMPNG = YES                                                      00000420
      KSYS = 8                                                          00000430
      NC = 8                                                            00000440
      NCLEAR = 3                                                        00000450
      NUNIT = 6                                                         00000460
```

```
C                                                                       00000470
      READ(5,5001,END=50)(LABEL(JA), JA = 1, 18)                        00000480
      READ(5,5001)       (TITLE (JA), JA = 1, 18)                       00000490
      READ(5,5003) RPM                                                  00000500
      READ(5,5010) CLEAR, PIN2$8                                        00000510
      READ(5,5002) MPRINT                                               00000520
      READ(5,5002) IDRAW                                                00000530
      READ(5,5002) AGTOUT                                               00000540
      READ(5,5001) CARDS, TAPE                                          00000550
      READ(5,5003) WTDEG                                                00000560
      READ(5,5005) KPRINT, NCOUNT                                       00000570
      READ(5,5002) IPRINT                                               00000580
      READ(5,5002) IPLOT                                                00000590
      READ(5,5004) IDEG                                                 00000600
      READ(5,5003) DELT                                                 00000610
      READ(5,5001)       (YNAME(JA,1 ),JA = 1, 18)                      00000620
      READ(5,5001)       (YNAME(JA,2 ),JA = 1, 18)                      00000630
      READ(5,5001)       (YNAME(JA,3 ),JA = 1, 18)                      00000640
      READ(5,5001)       (YNAME(JA,4 ),JA = 1, 18)                      00000650
      READ(5,5001)       (YNAME(JA,5 ),JA = 1, 18)                      00000660
      READ(5,5001)       (YNAME(JA,6 ),JA = 1, 18)                      00000670
      READ(5,5001)       (YNAME(JA,7 ),JA = 1, 18)                      00000680
      READ(5,5001)       (YNAME(JA,8 ),JA = 1, 18)                      00000690
      READ(5,5001)       (YNAME(JA,9 ),JA = 1, 18)                      00000700
      READ(5,5001)       (YNAME(JA,10),JA = 1, 18)                      00000710
      READ(5,5001)       (YNAME(JA,11),JA = 1, 18)                      00000720
      READ(5,5001)       (YNAME(JA,12),JA = 1, 18)                      00000730
      READ(5,5001)       (YNAME(JA,13),JA = 1, 18)                      00000740
      READ(5,5001)       (XNAME (JA), JA = 1, 18)                       00000750
C                                                                       00000760
CCC                                                                     00000770
C                                                                       00000780
                                                                        00000790
      ROCKER = REALTH(3) / REALTH(2)                                    00000800
      IF(CLEAR .GT. -10.0)  GO TO 20                                    00000810
      TITLE(4) = VLV                                                    00000820
C                                                                       00000830
   20 IF(PIN2$8 .EQ. NO)  GO TO 25                                      00000840
      LABEL(10) =  TWO1                                                 00000850
      LABEL(11) =  TWO2                                                 00000860
C                                                                       00000870
   25 WRITE(NUNIT,5009) AGTOUT,CARDS,TAPE,IPLOT,IDRAW,DAMPNG,PIN2$8,    00000880
     1                  MPRINT                                         00000890
      WRITE(NUNIT,5007) NUNIT,NTIME,KSYS,NCLEAR,NC,NCOUNT,IDEG          00000900
      WRITE(NUNIT,5008) RPM,CLEAR,WTDEG,AMP,DELT,ROCKER                 00000910
      WRITE(NUNIT,5008) (AXILTH(I), I = 1,4)                            00000920
      WRITE(NUNIT,5008) (REALTH(I), I = 1,4)                            00000930
C                                                                       00000940
```

```
      RETURN                                                            00000950
C                                                                       00000960
C                                                                       00000970
   50 IF( IUNIT .EQ. 4 )  END FILE 4                                    00000980
      IF( IUNIT .EQ. 4 )  END FILE 4                                    00000990
      IF( IUNIT .EQ. 4 )  REWIND 4                                      00001000
C                                                                       00001010
      STOP                                                              00001020
C                                                                       00001030
C                                                                       00001040
C                                                                       00001050
C                                                                       00001060
C                                                                       00001070
C                                                                       00001080
C-----------------------------------------------------------------------00001090
      END                                                               00001100
```

```
      SUBROUTINE MATRIX( COLM, COLC, COLK, SYSM, DAMP, STF, STFI, KSYS,  00000010
     1                   KSYSM1, C, IQ, MPRINT, LAYER, IDIM)            00000020
C                                                                        00000030
      IMPLICIT REAL*8(A-H,O-Z)                                           00000040
C                                                                        00000050
      INTEGER YES, C                                                     00000060
C                                                                        00000070
      DIMENSION COLM(KSYS,1), COLC(KSYS,1), COLK(KSYS,1),                00000080
     1          DAMP(KSYS,KSYS,1), STF(KSYS,KSYS,1), STFI(KSYSM1,1),     00000090
     2          SYSM(KSYS,KSYS,1), IQ(KSYS,1), LAYER(1), IDIM(1)         00000100
C                                                                        00000110
      COMMON NUNIT, IPRINT                                               00000120
C                                                                        00000130
      DATA YES/4HYES /, NO/4HNO  /                                       00000140
C                                                                        00000150
C                                                                        00000160
      KCOUNT = 1                                                         00000170
      LC = LAYER(C)                                                      00000180
C             ********************************************             00000190
CC            **                                          **             00000200
CCC           **   ESTABLISH THE 1X6 COLUMN MATRIX FROM   **             00000210
CCCC          **  THE SYSTEM M-C-K MATRICS WITHOUT ROW 1   **             00000220
CCCCC         **                                          **             00000230
CCCCCC        ********************************************             00000240
CCCCCC                                                                   00000250
CCCCCC                                                                   00000260
CCCCCC        ********************************************             00000270
CCCCCC        **                                          **             00000280
CCCCCC        **     ESTABLISH THE 6X6 MATRICS FROM THE   **             00000290
CCCCCC        ** SYSTEM M-C-K MATRICS WITHOUT ROW/COL 7    **             00000300
CCCCC         **                                          **             00000310
CCCC          ********************************************             00000320
C                                                                        00000330
   20 DO 200 JA = 1,KSYS                                                 00000340
      JC = IQ(JA,C)                                                      00000350
      IF(JC .EQ. 0)  GO TO 300                                           00000360
C                                                                        00000370
      DO 100 JB = 1,KSYS                                                 00000380
      JD = IQ(JB,C)                                                      00000390
      IF(JD .EQ. 0)  GO TO 150                                           00000400
C                                                                        00000410
      SYSM(JA,JB,C) = SYSM(JC,JD,LC)                                     00000420
      DAMP(JA,JB,C) = DAMP(JC,JD,LC)                                     00000430
      STF (JA,JB,C) = STF (JC,JD,LC)                                     00000440
  100 CONTINUE                                                           00000450
  150 IDIM(C) = KCOUNT                                                   00000460
```

```
      KCOUNT = KCOUNT + 1                                                00000470
C                                                                        00000480
      JCIQ = JC                                                          00000490
      IFOR = 1                                                           00000500
C                                                                        00000510
      IF(C .LE. 4)  IFOR = 7                                             00000520
      IF(C .EQ. 1)  JCIQ = IQ(JA,6)                                      00000530
      IF(C .EQ. 3)  JCIQ = IQ(JA,8)                                      00000540
C                                                                        00000550
      COLM(JA,C) = SYSM(JCIQ,IFOR,LC)                                    00000560
      COLC(JA,C) = DAMP(JCIQ,IFOR,LC)                                    00000570
      COLK(JA,C) = STF (JCIQ,IFOR,LC)                                    00000580
C                                                                        00000590
C                                                                        00000600
  200 CONTINUE                                                           00000610
  300 IF(MPRINT .EQ. NO)  GO TO 350                                      00000620
C                                                                        00000630
      CALL PRNTMX( COLM(1,C), COLC(1,C), COLK(1,C), SYSM(1,1,C),         00000640
     1             DAMP(1,1,C), STF(1,1,C), KSYS, C, IDIM(C)  )        00000650
C                                                                        00000660
C                                                                        00000670
  350 IF(C .GT. 1)  RETURN                                               00000680
C                                                                        00000690
      DO 400 JA = 1,KSYSM1                                               00000700
C                                                                        00000710
           DO 400 JB = 1,KSYSM1                                          00000720
           STFI(JA,JB) = STF(JA,JB,3)                                    00000730
C                                                                        00000740
  400 CONTINUE                                                           00000750
C                                                                        00000760
CCC                ********************************************        00000770
CCC                **                                        **        00000780
CCC                **           CALL SUBROUTINE DINVS          **      00000790
CCC                **  DINVS CALCULATES THE INVERSE STIFFNESS  **      00000800
CCC                **                MATRIX                    **      00000810
CCC                **        SEND STF - - RETURN STFI          **      00000820
CCC                **                                          **      00000830
CCC                ********************************************        00000840
C                                                                        00000850
      CALL DINVS(STFI,KSYSM1,KSYSM1)                                     00000860
C                                                                        00000870
      RETURN                                                             00000880
      END                                                                00000890
```

```
C
C-----------------------------------------------------------------
C
C        SUBROUTINE CODED BY DR. R. C. WINFREY AND R. ANDERSON
C                  MODIFIED BY C. W. GNILKA
C
C-----------------------------------------------------------------
C

      SUBROUTINE MCK( SYSM, DAMP, STF, KSYS, JC, N, NPRINT, COFD, PHI,   00000010
     1                ELAM, C)                                           00000020
C                                                                        00000030
      IMPLICIT REAL*8(A-H,O-Z)                                           00000040
C                                                                        00000050
      INTEGER YES, C                                                     00000060
C                                                                        00000070
      DIMENSION PHTINV(8,8),PHITM(8,8), PHITK(8,8), DIAGM(8,8),          00000080
     1          E(5), SEE(8,8), PHINV(8,8), PHI(KSYS,KSYS,1),            00000090
     2          SYSM(KSYS,KSYS,1), STF(KSYS,KSYS,1), DAMP(KSYS,KSYS,1),  00000100
     3          DIAGK(8,8), DIAGC(8,8), ZTA(8), BETA(8,8), L(8), Y(5),   00000110
     4          AM(5), AMM(5), DIA(5), ELAM(KSYS,1), PHTIDC(8,8)         00000120
C                                                                        00000130
      COMMON NUNIT, IPRINT                                               00000140
C                                                                        00000150
      DATA YES/4HYES /, NO/4HNO  /                                       00000160
C                                                                        00000170
C     LENGTH                                                             00000180
      DATA  Y/9.0D0, 1.0D0, 1.5D0, 36.0D0, 3.0D0/                        00000190
C                                                                        00000200
C                                                                        00000210
      DATA  AMM/5*0.283D0/,   E/5*3.0D7/                                 00000220
C                                                                        00000230
      DATA  DIA/0.3D0, 0.6D0, 0.6D0, 0.07D0, 0.3D0/                      00000240
C                                                                        00000250
      DATA  PI/3.14159265359D0/, GRAV/386.0D0/                           00000260
C                                                                        00000270
C                                                                        00000280
  330 FORMAT('0',//,10X,'ERROR RETURN FROM DVVS. NERR = ', I3,/// )      00000290
  700 FORMAT(' ',4X, 8(1PD15.8, 1X )  )                                  00000300
C                                                                        00000310
C                                                                        00000320
C                                                                        00000330
      IF(NPRINT .EQ. YES) WRITE(NUNIT,700) (ZTA(KA), KA = 1,JC)          00000340
      RAD = PI/180.0D0                                                   00000350
C     N IS THE NUMBER OF ELEMENTS                                        00000360
C     JC = SIZE OF K (OR M) AND NUMBER OF COL OF B                       00000370
C                                                                        00000380
```

```
C                                                                       00000390
      DO 5 I = 1, N                                                     00000400
      AM(I) = AMM(I) * PI * DIA(I)**2 * Y(I) /(4.0D0 * GRAV)            00000410
    5 CONTINUE                                                          00000420
C                                                                       00000430
      DO 10  I = 1, JC                                                  00000440
      ZTA(I) = 0.1D0                                                    00000450
C                                                                       00000460
      IF(C .EQ. 1)  ZTA(4) = 0.5D0                                      00000470
      IF(C .EQ. 3)  ZTA(1) = 0.5D0                                      00000480
      IF(C .EQ. 3)  ZTA(4) = 0.1D0                                      00000490
C     SET SYSTEM K (OR M) TO 0                                          00000500
C                                                                       00000510
      DO 10  J = 1, JC                                                  00000520
      SYSM(I,J,C) = 0.0D0                                               00000530
      STF(I,J,C) = 0.0D0                                                00000540
   10 CONTINUE                                                          00000550
C                                                                       00000560
C     CALCULATE  EACH  ELEMENT K (OR M)                                 00000570
      APYX = PI * E(3) * DIA(3)**4 / 64.0D0                             00000580
      APYY = PI * E(2) * DIA(2)**4 / 64.0D0                             00000590
C                                                                       00000600
      ONE   = E(1) * PI * DIA(1)**2 /( Y(1)*4.0D0 )                     00000610
      TWO   = 12.0D0 * APYY /( Y(2)**3 )                                00000620
      THREE =  6.0D0 * APYY /( Y(2)**2 )                                00000630
      FOUR  =  4.0D0 * APYY /  Y(2)                                     00000640
      FIVE  =  2.0D0 * APYY /  Y(2)                                     00000650
      SIX   = 12.0D0 * APYX /( Y(3)**3 )                                00000660
      SEVEN = E(5) * PI * DIA(5)**2 /( Y(5)*4.0D0 )                     00000670
      EIGHT =  6.0D0 * APYX /( Y(3)**2 )                                00000680
      ANINE =  4.0D0 * APYX /  Y(3)                                     00000690
      TEN   = E(4) * PI * DIA(4)**2 /( Y(4)*4.0D0 )                     00000700
      TEN = 254.0D0                                                     00000710
      ELVEN =  2.0D0 * APYX /  Y(3)                                     00000720
C                                                                       00000730
      STF(1,1,C) = ONE                                                  00000740
      STF(1,8,C) = -ONE                                                 00000750
      STF(2,2,C) = TWO                                                  00000760
      STF(2,3,C) = THREE                                                00000770
      STF(2,6,C) = THREE                                                00000780
      STF(3,3,C) = FOUR                                                 00000790
      STF(3,6,C) = FIVE                                                 00000800
      STF(4,4,C) = SIX + SEVEN + TEN                                    00000810
      STF(4,5,C) =-EIGHT                                                00000820
      STF(4,6,C) =-EIGHT                                                00000830
      STF(4,7,C) = SEVEN                                                00000840
      STF(5,5,C) = ANINE                                                00000850
      STF(5,6,C) = ELVEN                                                00000860
```

```
      STF(6,6,C) = ANINE + FOUR                                                 00000870
      STF(7,7,C) = SEVEN                                                        00000880
      STF(8,8,C) =  ONE                                                         00000890
C                                                                               00000900
      SYSM(1,1,C) =  AM(1) / 3.0D0                                              00000910
      SYSM(1,8,C) =  AM(1) / 6.0D0                                              00000920
      SYSM(2,2,C) =   156.0D0 * AM(2) / 420.0D0                                 00000930
      SYSM(2,3,C) =  AM(2) * 22.0D0 * Y(2) / 420.0D0                            00000940
      SYSM(2,6,C) = -AM(2) * 13.0D0 * Y(2) / 420.0D0                            00000950
      SYSM(3,3,C) =  AM(2) *  4.0D0 * Y(2)**2 / 420.0D0                         00000960
      SYSM(3,6,C) = -AM(2) *  3.0D0 * Y(2)**2 / 420.0D0                         00000970
      SYSM(4,4,C) =  AM(3) *156.0D0 / 420.0D0 + ( AM(5) + AM(4) )/ 3.0D000000980
      SYSM(4,5,C) = -AM(3) * 22.0D0 * Y(3) / 420.0D0                            00000990
      SYSM(4,6,C) =  AM(3) * 13.0D0 * Y(3) / 420.0D0                            00001000
      SYSM(4,7,C) = -AM(5) / 6.0D0                                              00001010
      SYSM(5,5,C) =  AM(3) *  4.0D0 * Y(3)**2 / 420.0D0                         00001020
      SYSM(5,6,C) = -AM(3) *  3.0D0 * Y(3)**2 / 420.0D0                         00001030
      SYSM(6,6,C) = SYSM(3,3,C) + SYSM(5,5,C)                                   00001040
      SYSM(7,7,C) =  AM(5) / 3.0D0                                              00001050
      SYSM(8,8,C) =  AM(1) / 3.0D0                                              00001060
C                                                                               00001070
      IF(C .EQ. 1)  GO TO 12                                                    00001080
      STF(1,2,3) = -ONE                                                         00001090
      STF(2,2,3) = ONE + TWO                                                    00001100
      SYSM(1,2,3) =  AM(1) / 6.0D0                                              00001110
      SYSM(2,2,3) =  AM(1) / 3.0D0 + 156.0D0*AM(2)/420.0D0                      00001120
C                                                                               00001130
      ZTA(1) = 0.1D0                                                            00001140
      ZTA(4) = 0.5D0                                                            00001150
   12 CONTINUE                                                                  00001160
      DO 20 JA = 1, JC                                                          00001170
C                                                                               00001180
   15 DO 20 JB = 1, JC                                                          00001190
      STF(JB,JA,C)  =  STF(JA,JB,C)                                             00001200
      SYSM(JB,JA,C) = SYSM(JA,JB,C)                                             00001210
      DIAGC(JA,JB)  = SYSM(JA,JB,C)                                             00001220
      PHINV(JA,JB) =  STF(JA,JB,C)                                              00001230
   20 CONTINUE                                                                  00001240
C                                                                               00001250
   24 CALL DVVS( PHINV, DIAGC, ELAM(1,C), PHI(1,1,C), JC, JC, JC, JC,           00001260
     1           KSYS, NERR)                                                    00001270
C                                                                               00001280
      IF( NERR .NE. 0)  WRITE(NUNIT,330) NERR                                   00001290
C                                                                               00001300
   25 DO 37  JA = 1, JC                                                         00001310
      ELAM(JA,C) = ELAM(JA,C)**.5                                               00001320
   37 CONTINUE                                                                  00001330
C                                                                               00001340
```

```
      DO 1310  JA = 1,JC                                                        00001350
C                                                                               00001360
   35 DO 1310  JB = 1,JC                                                        00001370
      PHTINV(JA,JB) = PHI(JB,JA,C)                                              00001380
      PHINV(JA,JB) = PHI(JA,JB,C)                                               00001390
C                                                                               00001400
      DIAGC(JA,JB) = 0.0D0                                                      00001410
 1310 CONTINUE                                                                  00001420
C                                                                               00001430
C                                                                               00001440
 1312 DO 1315  KA = 1,JC                                                        00001450
C                                                                               00001460
 1314 DO 1315  KB = 1,JC                                                        00001470
      PHITK(KA,KB) = 0.0D0                                                      00001480
      PHITM(KA,KB) = 0.0D0                                                      00001490
C                                                                               00001500
      DO 1315  KC = 1,JC                                                        00001510
      PHITM(KA,KB) = PHTINV(KA,KC)*SYSM(KC,KB,C) + PHITM(KA,KB)                 00001520
      PHITK(KA,KB) = PHTINV(KA,KC)* STF(KC,KB,C) + PHITK(KA,KB)                 00001530
C                                                                               00001540
 1315 CONTINUE                                                                  00001550
C                                                                               00001560
      DO 1318  KA = 1,JC                                                        00001570
C                                                                               00001580
      DO 1318  KB = 1,JC                                                        00001590
      DIAGK(KA,KB) = 0.0D0                                                      00001600
      DIAGM(KA,KB) = 0.0D0                                                      00001610
C                                                                               00001620
 1316 DO 1318  KC = 1,JC                                                        00001630
      DIAGM(KA,KB) = PHITM(KA,KC)*PHI(KC,KB,C) + DIAGM(KA,KB)                   00001640
      DIAGK(KA,KB) = PHITK(KA,KC)*PHI(KC,KB,C) + DIAGK(KA,KB)                   00001650
C                                                                               00001660
 1318 CONTINUE                                                                  00001670
C                                                                               00001680
      DO 1328  KA = 1,JC                                                        00001690
      DIAGC(KA,KA) = 2.0D0*ZTA(KA)*( DIAGM(KA,KA)*DIAGK(KA,KA) )**0.5D0         00001700
 1328 CONTINUE                                                                  00001710
C                                                                               00001720
 1326 CALL DINVS(PHTINV,JC,KSYS)                                                00001730
C                                                                               00001740
```

```
C                                                                       00001750
 1327 CALL DINVS(PHINV,JC,KSYS)                                         00001760
C                                                                       00001770
C                                                                       00001780
      DO 1322  KA = 1,JC                                                00001790
C                                                                       00001800
      DO 1322  KB = 1,JC                                                00001810
      PHTIDC(KA,KB) = 0.0D0                                             00001820
C                                                                       00001830
 1323 DO 1322  KC = 1,JC                                                00001840
      PHTIDC(KA,KB) = PHTINV(KA,KC)*DIAGC(KC,KB) + PHTIDC(KA,KB)        00001850
C                                                                       00001860
 1322 CONTINUE                                                          00001870
C                                                                       00001880
      DO 1324  KA = 1,JC                                                00001890
C                                                                       00001900
      DO 1324  KB = 1,JC                                                00001910
      SEE(KA,KB) = 0.0D0                                                00001920
C                                                                       00001930
1321  DO 1324  KC = 1,JC                                                00001940
      SEE(KA,KB) = PHTIDC(KA,KC)*PHINV(KC,KB) + SEE(KA,KB)              00001950
C                                                                       00001960
 1324 CONTINUE                                                          00001970
C                                                                       00001980
      DO  1325  KA = 1, JC                                              00001990
 1330 DO  1325  KB = 1, JC                                              00002000
      DAMP(KA,KB,C) = SEE(KA,KB)*COFD                                   00002010
 1325 CONTINUE                                                          00002020
C                                                                       00002030
      RETURN                                                            00002040
      END                                                               00002050
```

```
      SUBROUTINE MONTOR(NCLEAR, CONFIG, ICORD, F,  C, NPRINT, IDT, DTP,  00000010
     1           DTPMIN, IMPACT, Q, QSAV, FSAV, DT)                       00000020
C                                                                         00000030
      IMPLICIT REAL*8(A-H,O-Z)                                            00000040
C                                                                         00000050
      INTEGER YES, C, CONFIG(16,1)                                        00000060
C                                                                         00000070
      DIMENSION ICORD(NCLEAR,1), F(1), FSAV(1),DTP(1),  Q(1), QSAV(1),    00000080
     1          IMPACT(1)                                                00000090
C                                                                         00000100
      COMMON NUNIT, IPRINT                                                00000110
C                                                                         00000120
      DATA YES/4HYES /, NO/4HNO  /                                        00000130
C                                                                         00000140
 5000 FORMAT('0', 20X, 'MONITORING INDICATES MORE THAN ONE CONFIGURATION00000150
     1 CHANGE IN ONE TIME STEP')                                          00000160
 5001 FORMAT('0', 20X, '********** ERROR - - COMPUTER TRUNCATION - - KK  00000170
     1 NOT CORRECTLY SET **********')                                     00000180
 5002 FORMAT(' ',10X, 'DTP(', I2, ')=',1PD15.7, 15X, 'DTPMIN =', D15.7)   00000190
 5003 FORMAT(' ', 10X, 'INDEX OF DTP(I) FOR MIN IS', I2, ' AND IMPACT ='00000200
     1,  I2)                                                              00000210
C                                                                         00000220
      IDT = 0                                                             00000230
      EPS1 = 1.0D-1                                                       00000240
      EPS2 = 1.0D-6                                                       00000250
C                                                                         00000260
      DO  20  I = 1, NCLEAR                                               00000270
      DTP(I) = +1.0D0                                                     00000280
      IMPACT(I) = 0                                                       00000290
   20 CONTINUE                                                            00000300
C                                                                         00000310
      DO 23  KK = 1, NCLEAR                                               00000320
C                                                                         00000330
      INDEX = ICORD(KK,1)                                                 00000340
      NDEX = ICORD(KK,2)                                                  00000350
C                                                                         00000360
      IF( CONFIG(C,KK) .EQ. 0 )  GO TO 12                                 00000370
C                                                                         00000380
CC                ********************************************          00000390
CC                **                                        **          00000400
CC                **              FORCE MONITOR             **          00000410
CC                **                                        **          00000420
CC                ********************************************          00000430
C                                                                         00000440
      IF(F(INDEX) .GE. 0.0) GO TO 23                                      00000450
C                                                                         00000460
```

```
      FSAVE = FSAV( INDEX )                                              00000470
      FSEND = F( INDEX )                                                 00000480
C                                                                        00000490
      CALL DTPRIM( FSEND, KK, FSAVE, DT, DTP, NPRINT)                    00000500
      IDT = IDT + 1                                                      00000510
C                                                                        00000520
      GO TO 23                                                           00000530
C                                                                        00000540
C             ********************************************             00000550
C             **                                          **             00000560
C             **        DISPLACEMENT MONITOR              **             00000570
C             **                                          **             00000580
C             ********************************************             00000590
C                                                                        00000600
   12 DISPL = Q( INDEX ) - Q( NDEX )                                     00000610
      IF(DISPL .GE. 0.0)  GO TO  23                                      00000620
      IF( DABS(DISPL) .LE. EPS2)    GO TO 23                             00000630
C                                                                        00000640
      IMPACT(KK) = KK                                                    00000650
      DOLD = QSAV( INDEX ) - QSAV( NDEX )                                00000660
       IF(DOLD .LE. 0.0)  DOLD = 1.0D-10                                 00000670
C                                                                        00000680
      CALL DTPRIM( DISPL, KK, DOLD, DT, DTP, NPRINT)                     00000690
      IDT = IDT + 1                                                      00000700
C                                                                        00000710
   23 CONTINUE                                                           00000720
C                                                                        00000730
      DO  25  I = 1, NCLEAR                                              00000740
      IF(DTP(I) .LT. 0.1D0)  GO TO 50                                    00000750
   25 CONTINUE                                                           00000760
      IDT = -1                                                           00000770
C                                                                        00000780
      RETURN                                                             00000790
C                                                                        00000800
C                                                                        00000810
   50 DTPMIN = +1.0D6                                                    00000820
      DO 60  JA = 1, NCLEAR                                              00000830
      DTPMIN = DMIN1( DTPMIN, DTP(JA) )                                  00000840
      IF(NPRINT .EQ. YES) WRITE(NUNIT,5002) JA, DTP(JA),DTPMIN           00000850
   60 CONTINUE                                                           00000860
C                                                                        00000870
      IF(IDT .GT. 1   .AND.  NPRINT .EQ. YES)  WRITE(NUNIT,5000)         00000880
C                                                                        00000890
      DO  70  KK = 1, NCLEAR                                             00000900
      IF(DTPMIN .EQ. DTP(KK) )  GO TO 80                                 00000910
   70 CONTINUE                                                           00000920
C                                                                        00000930
      WRITE(NUNIT,5001)                                                  00000940
```

```
C                                                                       00000950
CCCCCC            ********************************************          00000960
CCCCCC            **                                        **          00000970
CCCCCC            **          CHANGE CONFIGURATION          **          00000980
CCCCCC            **                                        **          00000990
CCCCCC            ********************************************          00001000
C                                                                       00001010
   80 CALL SHIFT( C, KK, CONFIG, NPRINT)                                00001020
      IDT = KK                                                          00001030
C                                                                       00001040
      IF(NPRINT .EQ. NO)  RETURN                                        00001050
      WRITE(NUNIT,5003) KK, IMPACT(KK)                                  00001060
C                                                                       00001070
      RETURN                                                            00001080
      END                                                               00001090
```



```
      SUBROUTINE CAM(WT,AMP,AMPW,XZERO,W2,Q,QD,QDD)                     00000010
C                                                                       00000020
      IMPLICIT REAL*8(A-H,O-Z)                                          00000030
C                                                                       00000040
      INTEGER YES                                                       00000050
C                                                                       00000060
      DIMENSION Q(1), QD(1), QDD(1)                                     00000070
C                                                                       00000080
      COMMON NUNIT, IPRINT                                              00000090
C                                                                       00000100
      DATA  YES/4HYES /, NO/4HNO  /                                     00000110
C                                                                       00000120
      AMPSIN = AMP*DSIN(WT)                                             00000130
      Q(9)   = AMPSIN + XZERO                                           00000140
      QD(9)  = AMPW*DCOS(WT)                                            00000150
      QDD(9) = AMPSIN*W2                                                00000160
C                                                                       00000170
      RETURN                                                            00000180
      END                                                               00000190
```

```
      SUBROUTINE NEWMRK( ISYS, KSYS,     C,      STF , DAMP, SYSM, DP,    00000010
     1  DT, DT02, DT206, DT203, Q, QD, QDD, BMIV, DA, DV, NC,             00000020
     2  ALFA,BETA,CONFIG,F,ICORD,NCLEAR,NPRINT,IQ,COLM,COLC,COLK,IDP,     00000030
     3  PIN2$8, IDIM, LAYER, IGU, QDDSAV, QDSAV, QSAV, SCALE, IMP)        00000040
C                                                                        00000050
      IMPLICIT REAL*8(A-H,O-Z)                                           00000060
C                                                                        00000070
      INTEGER C, CONFIG(16,1), YES, PIN2$8                               00000080
C                                                                        00000090
      DIMENSION BMIV(KSYS,KSYS), DA(KSYS,KSYS), DV(KSYS,KSYS),           00000100
     1  STF(KSYS,KSYS,1), DAMP(KSYS,KSYS,1), SYSM(KSYS,KSYS,1),          00000110
     2  ALFA(1), BETA(1), Q(1), QD(1), QDD(1), DP(1),                     00000120
     3  ICORD(NCLEAR,1), F(1), IQ(KSYS,1), COLM(KSYS,1), COLC(KSYS,1),    00000130
     4  COLK(KSYS,1), IDP(KSYS,1), IDIM(1), LAYER(1), QDDSAV(1),          00000140
     5  QDSAV(1), QSAV(1)                                                 00000150
C                                                                        00000160
      COMMON NUNIT, IPRINT                                               00000170
C                                                                        00000180
      DATA  YES/4HYES /, NO/4HNO  /                                      00000190
C                                                                        00000200
 5000 FORMAT('0',10X,'ICORD(',I1,')=',I3)                                00000210
 5007 FORMAT(' ',10X, 'SYSM(', I1, ',', I1, ')=',1PD15.8,4X,             00000220
     1                'DAMP(', I1, ',', I1, ')=',1PD15.8,4X,             00000230
     2                 'STF(', I1, ',', I1, ')=',1PD15.8)                00000240
 5008 FORMAT('0','ALFA*',8(3X,1PD12.5) )                                 00000250
 5009 FORMAT(' ','BETA*',8(3X,1PD12.5) )                                 00000260
 5010 FORMAT(' ',1P7D18.6)                                               00000270
 5011 FORMAT(' ',9X,'BMIV',14X,'DP',16X,'DA',14X,'ALFA',14X,'DV',        00000280
     1  15X,'BETA',12X,'QDD')                                            00000290
 5015 FORMAT('0')                                                        00000300
 5027 FORMAT('0',///,10X,'CONFIGURATION MATRIX' )                        00000310
 5028 FORMAT('0',//,10X,2(4X,I1) )                                       00000320
 5037 FORMAT(' ','FORCE',1P7D16.8, D15.7)                                00000330
 5041 FORMAT('0','********************* IN SUBROUTINE NEWMRK - -  C =', 00000340
     1    I2, '****************')                                        00000350
 5042 FORMAT(' ','********************* RETURNED TO MAIN  OR  BACKSTEP ', 00000360
     1    'FROM NEWMRK  *******',//)                                     00000370
 5043 FORMAT(' ', 20X, 'C =', I2, 10X, ' NCLEAR =',I2)                   00000380
 5044 FORMAT(' ',30X, ' CONFIG ELEMENT - -',I2,',',I2)                   00000390
 5045 FORMAT(' ', 10X, 'IMPACT ACCEL AT COORD 2 IS ', D15.7, ' BASED ON' 00000400
     2          ,F2.3, ' TIMES  THE OLD VELOCITY', 1PD15.7)             00000410
C                                                                        00000420
C                                                                        00000430
      IF(NPRINT .EQ. YES)  WRITE(NUNIT,5041) C                           00000440
C                                                                        00000450
   25 DO  50  I = 1,KSYS                                                 00000460
```

```
      DP(I) = 0.0D0                                                    00000470
   50 CONTINUE                                                         00000480
C                                                                      00000490
      IF(C .EQ. 1  .OR.  C .EQ. 3)  GO TO 500                          00000500
C                                                                      00000510
      DO  300  JA = 1,NCLEAR                                           00000520
      KDP = IDP(C,JA)                                                  00000530
      IF(KDP .NE. 0)  GO TO 325                                        00000540
C                                                                      00000550
  300 CONTINUE                                                         00000560
C                                                                      00000570
  325 KC = C                                                           00000580
C                                                                      00000590
  350 ACCEL = QDD(KDP)                                                 00000600
      VEL   =  QD(KDP)                                                 00000610
      DIST  =   Q(KDP)                                                 00000620
C                                                                      00000630
      DO  400  JA = 1, ISYS                                            00000640
      CSYSM = COLM(JA,KC)                                              00000650
      CDAMP = COLC(JA,KC)                                              00000660
      CSTFF = COLK(JA,KC)                                              00000670
      DP(JA) = CSYSM*ACCEL + CDAMP*VEL + CSTFF*DIST + DP(JA)           00000680
  400 CONTINUE                                                         00000690
C                                                                      00000700
  425 IF(KC .NE. C)  GO TO 500                                         00000710
      IF(C .EQ. 6)  KC = 1                                             00000720
      IF(C .EQ. 8)  KC = 3                                             00000730
      KDP = 7                                                          00000740
      IF(KC .NE. C)  GO TO 350                                         00000750
  500 CONTINUE                                                         00000760
C                                                                      00000770
  600 DO  700  JA = 1, ISYS                                            00000780
      IA = IQ(JA,C)                                                    00000790
      ACCEL = QDDSAV(IA)                                               00000800
      VEL   =  QDSAV(IA)                                               00000810
C                                                                      00000820
      ALFA(JA) = ACCEL*DT02  + VEL                                     00000830
      BETA(JA) = ACCEL*DT203 + VEL*DT + QSAV(IA)                       00000840
  700 CONTINUE                                                         00000850
C                                                                      00000860
      IF(NPRINT .EQ. NO)  GO TO 750                                    00000870
C                                                                      00000880
      WRITE(NUNIT,5008) ( ALFA(JA),  JA = 1,ISYS )                     00000890
      WRITE(NUNIT,5009) ( BETA(JA),  JA = 1,ISYS )                     00000900
      WRITE(NUNIT,5011)                                                00000910
C                                                                      00000920
  750 DO  900  JA = 1, ISYS                                            00000930
C                                                                      00000940
```

```
      IA = IQ(JA,C)                                                          00000950
      QDD(IA) = 0.0D0                                                        00000960
C                                                                            00000970
      DO  800  JB = 1, ISYS                                                  00000980
      QDD(IA) = QDD(IA) - BMIV(JA,JB)*DP(JB) - DA(JA,JB)*ALFA(JB)            00000990
     1   - DV(JA,JB)*BETA(JB)                                                00001000
C                                                                            00001010
      IF(NPRINT .EQ. NO)  GO TO 800                                          00001020
      WRITE(NUNIT,5010) BMIV(JA,JB),DP(JB),DA(JA,JB),ALFA(JB),DV(JA,JB),     00001030
     1   BETA(JB), QDD(IA)                                                   00001040
C                                                                            00001050
  800 CONTINUE                                                               00001060
C                                                                            00001070
      IF(NPRINT .EQ. YES)  WRITE(NUNIT,5015)                                 00001080
  900 CONTINUE                                                               00001090
C                                                                            00001100
      IF(IMP .NE. 2)  GO TO 950                                              00001110
      QDD(2) = (SCALE - 1.0D0) * QDSAV(2) / DT                               00001120
      WRITE(NUNIT,5045) QDD(2), SCALE, QDSAV(2)                              00001130
      IMP = -10                                                              00001140
  950 DO  1000  JA = 1, ISYS                                                 00001150
      IA = IQ(JA,C)                                                          00001160
      QD(IA) = ALFA(JA) + QDD(IA)*DT02                                       00001170
      Q (IA) = BETA(JA) + QDD(IA)*DT206                                      00001180
C                                                                            00001190
 1000 CONTINUE                                                               00001200
      IF(IMP .NE. -10) GO TO 1050                                            00001210
      WRITE(NUNIT,5046) QD(2)                                                00001220
 5046 FORMAT(' ', 10X, 'NEW CALCULATED VELOCITY OF COORD. TWO IS  ',         00001230
     1        1PD15.7)                                                       00001240
      IMP = 0                                                                00001250
 1050 CONTINUE                                                               00001260
C                                                                            00001270
      LC = LAYER(C)                                                          00001280
      IF(LC .EQ. 3)  GO TO 1170                                              00001290
 1150 IF(PIN2$8 .EQ. NO)  GO TO 1175                                         00001300
C                                                                            00001310
 1170 CALL ADJUST(8,2, Q, QD, QDD, Q, QD, QDD)                               00001320
      LC = 3                                                                 00001330
 1175 CONTINUE                                                               00001340
      IF(IGU .EQ. YES)  LC = 1                                               00001350
      ILC = IDIM(LC)                                                         00001360
C                                                                            00001370
      DO  1300  IA = 1, NCLEAR                                               00001380
      KK = ICORD(IA,1)                                                       00001390
      F( KK) = 0.0D0                                                         00001400
C                                                                            00001410
      DO  1200  JA = 1, ILC                                                  00001420
```

```
      F(KK) = F(KK ) + SYSM(KK,JA,LC)*QDD(JA)                          00001430
     1    + DAMP(KK,JA,LC)*QD(JA) + STF(KK,JA,LC)*Q(JA)               00001440
 1200 CONTINUE                                                        00001450
C                                                                     00001460
 1300 CONTINUE                                                        00001470
 1350 IF(PIN2$8 .EQ. NO)  GO TO 1375                                  00001480
C                                                                     00001490
      F(2) = 0.0D0                                                    00001500
      F(8) = 0.0D0                                                    00001510
C                                                                     00001520
 1375 CONTINUE                                                        00001530
      IF(NPRINT .EQ. NO)  RETURN                                      00001540
      WRITE(NUNIT,5037)    ( F(JQ), JQ = 1, KSYS )                    00001550
C                                                                     00001560
      WRITE(NUNIT,5042)                                               00001570
C                                                                     00001580
      RETURN                                                          00001590
      END                                                             00001600
```

```
      SUBROUTINE  OLPLOT(X,Y,N,XMAX,XMIN,YMAX,YMIN,IRYP1, GRID,XSCALE,   00000010
     1                   MODCUR, NPRINT, LINES)                          00000020
C               **********************************************            00000030
CC              **                                          **            00000040
CCC             **         THIS  SUBROUTINE                 **            00000050
CCCC            **       PLOTS A SINGLE PRECISION FUNCTION  **            00000060
CCCCC           **  LENGTHWISE ON UP TO 6 PAGES OF OUTPUT   **            00000070
CCCC            **                                          **            00000080
C               **********************************************            00000090
      INTEGER*2 GRID,BLANK,DASH,SLINE,YCHAR(4)/1H.,1H+,1H*,1HX/           00000100
      DIMENSION GRID(LINES,1),YSCALE(5),XSCALE(1)                         00000110
      DIMENSION Y(1),X(1)                                                 00000120
      DATA DOT,BLANK,DASH,SLINE/Z4B40,Z4040,Z6D40,Z4F40/                  00000130
      COMMON NUNIT, IPPINT                                                00000140
      NDATA = N                                                           00000150
      KKZ = 1                                                             00000160
C                                                                         00000170
CCC   RY IS THE NUMBER OF LENGTHWISE LINES OF OUTPUT PLOT DESIRED         00000180
C                                                                         00000190
      RY = FLOAT(IRYP1 - 1 )                                              00000200
      IXSC = IRYP1/10 + 1                                                 00000210
      IERR=0                                                              00000220
C                                                                         00000230
CCC                                                                       00000240
CCCC                                                                      00000250
CCCCC GRID IS THE MATRIX USED TO PLOT THE POINTS                          00000260
CCCCC                                                                     00000270
CCCCC CHECKING Y AND X POINTS AND PLOTTING THOSE OUT OF RANGE             00000280
CCCC  AT THE MARGIN                                                       00000290
C                                                                         00000300
      DO 30 I=1,NDATA,KKZ                                                 00000310
      IF(Y(I)-YMAX) 205,205,220                                           00000320
  220 Y  (I)=YMAX                                                         00000330
      IERR=IERR+1                                                         00000340
      GOTO 210                                                            00000350
  205 IF(Y(I)-YMIN)203,210,210                                            00000360
  203 Y  (I)=YMIN                                                         00000370
      IERR=IERR+1                                                         00000380
  210 IF(X(I)-XMAX)215,215,212                                            00000390
  212 X  (I)=XMAX                                                         00000400
      IERR=IERR+1                                                         00000410
      GOTO 30                                                             00000420
  215 IF(X(I)-XMIN)217,  30,30                                            00000430
  217 X  (I)=XMIN                                                         00000440
      IERR=IERR+1                                                         00000450
C                                                                         00000460
```

```
   30 CONTINUE                                                          00000470
C                                                                       00000480
CC      PLOTTING Y AND X AYIS , IF NECESSARY                            00000490
C                                                                       00000500
        YRANGE=YMAX-YMIN                                                00000510
        XRANGE=XMAX-XMIN                                                00000520
        IF (XRANGE.NE.0.)  GO TO 298                                    00000530
        XMIN=YMIN                                                       00000540
        XMAX=YMAX                                                       00000550
        XRANGE=YRANGE                                                   00000560
        GO TO 299                                                       00000570
  298   IF (YRANGE.NE.0.)  GO TO 299                                    00000580
        YMIN=XMIN                                                       00000590
        YMAX=XMAX                                                       00000600
        YRANGE=XRANGE                                                   00000610
C                                                                       00000620
CC      BLANKING OUT MATRIX-(GRID)                                      00000630
C                                                                       00000640
  299   DO 300 I=1,IRYP1                                                00000650
        DO 301 JJ=1,81                                                  00000660
  301   GRID(I,JJ)=BLANK                                                00000670
  300   CONTINUE                                                        00000680
        XTEST=XMAX*XMIN                                                 00000690
        YTEST=YMAX*YMIN                                                 00000700
        IF(YTEST)1,222,222                                              00000710
  222   IF(XTEST)333,444,444                                            00000720
    1   IXAXIS=80. *(-YMIN)/YRANGE+1.5                                  00000730
        DO 40 I=1,IRYP1                                                 00000740
   40   GRID(I,IXAXIS)=SLINE                                            00000750
        GOTO 222                                                        00000760
  333   IYAXIS=RY *XMAX/XRANGE+1.5                                      00000770
        DO 60 I=1,81                                                    00000780
   60   GRID(IYAXIS,I)=DASH                                             00000790
C                                                                       00000800
CC      PLACING POINTS IN THEIR PROPER GRID POSITIONS                   00000810
  444   IF(MODCUR.EQ.0.OR.MODCUR.EQ.1)JSET=0                            00000820
        JSET=JSET+1                                                     00000830
        IF(JSET.GT.4) JSET=1                                            00000840
        DO 700 I=1,NDATA,KKZ                                            00000850
        IPTY=RY *(X(I)-XMIN)/XRANGE+1.5                                 00000860
        IPTX=80. *(Y(I)-YMIN)/YRANGE+1.5                                00000870
        IF(IPTY.GT.IRYP1.OR.IPTX.GT.81) GO TO 70                        00000880
        IF(IPTY.LE.0.OR.IPTX.LE.0)GO TO 70                              00000890
        GRID(IPTY,IPTX) = YCHAR(JSET)                                   00000900
        GO TO 700                                                       00000910
   70   IERR=IERR+1                                                     00000920
  700   CONTINUE                                                        00000930
C                                                                       00000940
```

```
C      COMPUTE PROPER SCALE NUMBERS                                      00000950
C                                                                        00000960
       IF(MODCUR.EQ.0.OR.MODCUR.EQ.1) GO TO 8000                         00000970
       IF(MODCUR.EQ.2) RETURN                                            00000980
       GO TO 922                                                         00000990
 8000  YINCR=YRANGE/4.                                                   00001000
       XINCR=XRANGE/FLOAT(IXSC-1)                                        00001010
       YSCALE(1)=YMAX                                                    00001020
       XSCALE(1)=XMIN                                                    00001030
       DO 80 I=2,5                                                       00001040
    80 YSCALE(I)=YSCALE(I-1)-YINCR                                       00001050
       DO 81 I=2,IXSC                                                    00001060
    81 XSCALE(I)=XSCALE(I-1)+XINCR                                       00001070
C                                                                        00001080
CC     OUTPUT SECTION WITH GRAPH                                         00001090
C                                                                        00001100
       IF(MODCUR.EQ.0.OR.MODCUR.EQ.3)GO TO 922                           00001110
       RETURN                                                            00001120
    17 FORMAT(12X,                                                       00001130
      1          1P E10.3,4(10X,E10.3)/15X,2H**,8(10H+*********),3H+**)  00001140
 922  WRITE(6,17) YSCALE(5),YSCALE(4),YSCALE(3),YSCALE(2),YSCALE(1)     00001150
       II=1                                                              00001160
       I=0                                                               00001170
       DO 101 IK=1,IRYP1                                                 00001180
       IF(I)91,91,92                                                     00001190
    91 WRITE(6,18) XSCALE(II),(GRID(IK,IY),IY=1,81),XSCALE(II)           00001200
 18    FORMAT(3X,1P                                                      00001210
      1          E10.3,2X,1H+,1X,81A1,1X,1H+,2X,E10.3)                  00001220
       II=II+1                                                           00001230
       GOTO 102                                                          00001240
    92 WRITE(6,19) (GRID(IK,IY),IY=1,81)                                 00001250
    19 FORMAT(15X,1H*,1X,81A1,1X,1H*)                                    00001260
   102 I=I+1                                                             00001270
       IF(I-10)101,103,103                                               00001280
   103 I=0                                                               00001290
   101 CONTINUE                                                          00001300
       WRITE(6,22) YSCALE(5),YSCALE(4),YSCALE(3),YSCALE(2),YSCALE(1)     00001310
    22 FORMAT(15X,2H**,8(10H+*********),3H+**/   1P                      00001320
      1                                        12X,E10.3,4(10X,E10.3))   00001330
       IF(IERR) 1000,1000,1001                                           00001340
 1001  WRITE(6,20) IERR                                                  00001350
   20  FORMAT(10X 'NUMBER OF POINTS OUT OF RANGE ='  I4)                 00001360
C                                                                        00001370
 1000  RETURN                                                            00001380
       END                                                               00001390
```

```
      SUBROUTINE PRINT(KSYS, ISYS, C, SYSM, DAMP, STF, BMIV, DA, DV,    00000010
     1           CONFIG, PHI, ELAM, STFI, STFRI, WTSTOP, WTPRNT, LABEL,  00000020
     2           YNAME, XNAME, TITLE,                                    00000030
     3           AGTOUT, CARDS, TAPE, IPLOT, IDRAW, DAMPNG, RPM, CLEAR,  00000040
     4           AMP, DELT, ROCKER, AXILTH, REALTH, NTIME, NC,           00000050
     5           NCLEAR, KSYSM1, COLM, COLC, COLK, COFD, ICORD,          00000060
     6           LAYER, IDP, IQ, IDIM, KSYSM2, PIN2$8, XZERO, FZERO,     00000070
     7           MPRINT)                                                 00000080
C                                                                        00000090
      IMPLICIT REAL*8(A-H,O-Z)                                           00000100
C                                                                        00000110
      REAL*4 LABEL,TITLE,XNAME,YNAME                                     00000120
C                                                                        00000130
      INTEGER YES,AGTOUT,DAMPNG,TAPE,CARDS,SEAT,C,CONFIG(16,1),PIN2$8    00000140
C                                                                        00000150
      DIMENSION PHI(KSYS,KSYS), ELAM(KSYS), SYSM(KSYS,KSYS),             00000160
     1           DAMP(KSYS,KSYS),   STF(KSYS,KSYS),   BMIV(KSYS,KSYS),  00000170
     2           DA(KSYS,KSYS),   DV(KSYS,KSYS),                        00000180
     3           STFI(KSYSM1,1), STFRI(KSYSM2,1), LABEL(1), TITLE(1),    00000190
     4           YNAME(20,1), AXILTH(1), REALTH(1),                      00000200
     5           XNAME(1), COLM(KSYS,1), COLC(KSYS,1), COLK(KSYS,1),     00000210
     6           ICORD(NCLEAR,1)                                         00000220
      DIMENSION LAYER(1), IDP(  KSYS,1), IQ(KSYS,1), IDIM(1)             00000230
C                                                                        00000240
      COMMON NUNIT, IPRINT                                               00000250
C                                                                        00000260
      DATA  YES/4HYES /, NO/4HNO  /                                      00000270
C                                                                        00000280
  620 FORMAT('0',10X,' MODE SHAPES-(PHI)',/)                             00000290
  660 FORMAT('0',10X,' NATURAL FREQ-(WN)',/)                             00000300
 1020 FORMAT('0',50X,'- ( BMIV ) -' ,//)                                 00000310
 1030 FORMAT(' ',20X, 1P8D10.2)                                          00000320
 1040 FORMAT('0',50X,'- ( DA ) -' ,//)                                   00000330
 1049 FORMAT('1', //////)                                                00000340
 1050 FORMAT('0', 40X, ' CONFIGURATION AND MATRIX LAYER =', I3,//,50X,   00000350
     1   'MATRICES ARE',I3,'X',I1,//)                                    00000360
 1060 FORMAT('0',50X,'- ( DV ) -' ,//)                                   00000370
 1070 FORMAT('0',//, 50X, '--- SYSM --- ',//)                            00000380
 1071 FORMAT('0',//,50X, ' --- DAMP ---',//)                             00000390
 1072 FORMAT('0',//,50X, ' --- STF ---',//)                              00000400
 5000 FORMAT('0', 2(10X,'ICORD(',I1,',' ,I1,  ')=',I3) )                00000410
 5001 FORMAT('1', ////////)                                              00000420
```

```
 5002 FORMAT('0')                                                        00000430
 5003 FORMAT('0', 20X, ' COORDINATES 2 AND 8 ARE PINED - - TWO ',        00000440
     1       'CLEARANCE PROBLEM')                                        00000450
 5004 FORMAT('0', 20X, ' COORDINATES 2 AND 8 ARE NOT PINED - - THREE ',  00000460
     1       'CLEARANCE PROBLEM')                                        00000470
 5010 FORMAT('0',//,20X,5HRPM =,0PF9.2,                                  00000480
     1    5X15HDAMPING COEF. =,0PF6.3,5X,7HCLEAR =,0PF6.3)               00000490
 5017 FORMAT('0', 20X, ' XZERO=', 1PD15.7,    '    FZERO =', D15.7)      00000500
 5020 FORMAT('0',20X,' AGT OUTPUT REQUESTED')                            00000510
 5021 FORMAT('0',20X,' NO AGT OUTPUT REQUESTED')                         00000520
 5022 FORMAT('0',20X,' AGT OUTPUT ON MAGNETIC TAPE')                     00000530
 5023 FORMAT('0',20X,' AGT OUTPUT ON PUNCHED CARDS')                     00000540
 5024 FORMAT('0',20X,' DAMPING REQUESTED')                               00000550
 5025 FORMAT('0',20X,'NO DAMPING REQUESTED')                             00000560
 5026 FORMAT('0',20X,18A4)                                               00000570
 5027 FORMAT('1',///,10X,'CONFIGURATION MATRIX' )                        00000580
 5028 FORMAT('0',//,10X,3(4X,I1) )                                       00000590
 5041 FORMAT('0',20X,' VALVE SEAT IMPOSED WITH AN INITIAL CLEARANCE OF '00000600
     1      , F5.2, ' INCHES' )                                         00000610
 5042 FORMAT('0', 20X, 'NO VALVE SEAT')                                  00000620
 5043 FORMAT(' ',//,10X,'COL-M-C-K ',//,6(10X,1P3D18.9,//)  )            00000630
 5044 FORMAT(' ',  1P7D18.9)                                             00000640
 5045 FORMAT('0',//,20X,'- - - - -  STFI - - - - - ',//)                 00000650
 5046 FORMAT('0',//,20X,'- - - -  STFRI - - - - -  ', //)                00000660
 5047 FORMAT('0',20X,' CALCOMP GRAPH DESIRED ')                          00000670
 5048 FORMAT('0',20X,' CALCOMP GRAPH NOT DESIRED ')                      00000680
 5050 FORMAT('0', 30X,  'MATRIX  - LAYER -' )                            00000690
 5051 FORMAT('0', 35X, I1)                                               00000700
 5052 FORMAT('0', 30X,  'MATRIX  - IDP -' )                              00000710
 5053 FORMAT('0', 30X, 3( I2, 2X) )                                      00000720
 5054 FORMAT('1',///, 30X,  'MATRIX  - IQ -' )                           00000730
 5055 FORMAT('0', 25X, 8( I1, 2X) )                                      00000740
 5056 FORMAT('0', 30X,  'MATRIX  - IDIM -' )                             00000750
 5057 FORMAT('0', 35X, I1 )                                              00000760
 5058 FORMAT('0', ///, 30X, ' MATRIX - ICORD -')                         00000770
 5312 FORMAT('0', 5X, 'WTSTOP =',1PD18.8, 5X, 'WTPRNT =',D18.8)          00000780
C                                                                        00000790
C                                                                        00000800
      IF(C .EQ. 3)  GO TO 358                                            00000810
      IF(C .EQ. 2  .OR.  C .GE. 4)  GO TO 359                            00000820
C                                                                        00000830
      WRITE(NUNIT,5001)                                                  00000840
C                                                                        00000850
```

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C                                                                       00000860
      WRITE(NUNIT,5026) (  LABEL(JA), JA = 1,18 )                       00000870
      WRITE(NUNIT,5026) (  TITLE(JA), JA = 1,18 )                       00000880
      WRITE(NUNIT,5026) ( YNAME(JA,1 ),JA = 1,18 )                      00000890
      WRITE(NUNIT,5026) ( YNAME(JA,2 ),JA = 1,18 )                      00000900
      WRITE(NUNIT,5026) ( YNAME(JA,3 ),JA = 1,18 )                      00000910
      WRITE(NUNIT,5026) ( YNAME(JA,4 ),JA = 1,18 )                      00000920
      WRITE(NUNIT,5026) ( YNAME(JA,5 ),JA = 1,18 )                      00000930
      WRITE(NUNIT,5026) ( YNAME(JA,6 ),JA = 1,18 )                      00000940
      WRITE(NUNIT,5026) ( YNAME(JA,7 ),JA = 1,18 )                      00000950
      WRITE(NUNIT,5026) ( YNAME(JA,8 ),JA = 1,18 )                      00000960
      WRITE(NUNIT,5026) ( YNAME(JA,9 ),JA = 1,18 )                      00000970
      WRITE(NUNIT,5026) ( YNAME(JA,10),JA = 1,18 )                      00000980
      WRITE(NUNIT,5026) ( YNAME(JA,11),JA = 1,18 )                      00000990
      WRITE(NUNIT,5026) ( YNAME(JA,12),JA = 1,18 )                      00001000
      WRITE(NUNIT,5026) ( YNAME(JA,13),JA = 1,18 )                      00001010
C                                                                       00001020
      IF( AGTOUT .EQ. YES )  WRITE(NUNIT,5020)                          00001030
      IF( AGTOUT .EQ. NO  )  WRITE(NUNIT,5021)                          00001040
C                                                                       00001050
      IF( TAPE .EQ. YES )   WRITE(NUNIT,5022)                           00001060
C                                                                       00001070
      IF( CARDS .EQ. YES )   WRITE(NUNIT,5023)                          00001080
C                                                                       00001090
      IF( DAMPNG .EQ. NO )  WRITE(NUNIT,5025)                           00001100
      IF( DAMPNG .EQ. YES)  WRITE(NUNIT,5024)                           00001110
C                                                                       00001120
      IF(IDRAW .EQ. YES)  WRITE(NUNIT,5047)                             00001130
      IF(IDRAW .EQ. NO )  WRITE(NUNIT,5048)                             00001140
C                                                                       00001150
      IF(CLEAR .LE. -10.0)  WRITE(NUNIT,5042)                           00001160
      IF(CLEAR .GT. -10.0)  WRITE(NUNIT,5041)  CLEAR                    00001170
C                                                                       00001180
      IF(PIN2$8 .EQ. YES)  WRITE(NUNIT,5003)                            00001190
      IF(PIN2$8 .EQ.  NO)  WRITE(NUNIT,5004)                            00001200
C                                                                       00001210
C                                                                       00001220
      WRITE(NUNIT,5010)       RPM,COFD , CLEAR                          00001230
      WRITE(NUNIT,5017)  XZERO, FZERO                                   00001240
      IF(MPRINT .EQ. NO)  RETURN                                        00001250
C                                                                       00001260
      WRITE(NUNIT,5027)                                                 00001270
      DO  80  JA = 1, NC                                                00001280
      WRITE(NUNIT,5028)  (CONFIG(JA,JB), JB = 1,NCLEAR)                 00001290
```

```
   80 CONTINUE                                                          00001300
C                                                                       00001310
      WRITE(NUNIT,5050)                                                 00001320
      DO  700  JA = 1, KSYS                                             00001330
      WRITE(NUNIT,5051)  LAYER(JA)                                      00001340
  700 CONTINUE                                                          00001350
C                                                                       00001360
      WRITE(NUNIT,5002)                                                 00001370
      WRITE(NUNIT,5052)                                                 00001380
      DO  710  JA = 1, KSYS                                             00001390
      WRITE(NUNIT,5053)  (IDP(JA,JB), JB = 1, NCLEAR)                   00001400
  710 CONTINUE                                                          00001410
C                                                                       00001420
      WRITE(NUNIT,5054)                                                 00001430
      DO  720  JA = 1, KSYS                                             00001440
      WRITE(NUNIT,5055)  (IQ(JA,JB), JB = 1, KSYS)                      00001450
  720 CONTINUE                                                          00001460
C                                                                       00001470
      WRITE(NUNIT,5002)                                                 00001480
      WRITE(NUNIT,5056)                                                 00001490
      DO  730  JA = 1, KSYS                                             00001500
      WRITE(NUNIT,5057)  IDIM(JA)                                       00001510
  730 CONTINUE                                                          00001520
C                                                                       00001530
      WRITE(NUNIT,5058)                                                 00001540
      DO  740  JA = 1, NCLEAR                                           00001550
      WRITE(NUNIT,5053) (ICORD(JA,JB), JB = 1,2)                        00001560
  740 CONTINUE                                                          00001570
C                                                                       00001580
      WRITE(NUNIT,5001)                                                 00001590
C                                                                       00001600
      WRITE(NUNIT,5045)                                                 00001610
C                                                                       00001620
      DO  221  JA = 1,KSYSM1                                            00001630
      WRITE(NUNIT,5044)  (STFI(JA,JB), JB = 1,KSYSM1)                   00001640
  221 CONTINUE                                                          00001650
C                                                                       00001660
      WRITE(NUNIT,5046)                                                 00001670
C                                                                       00001680
      DO  7  JA = 1,KSYSM2                                              00001690
      WRITE(NUNIT,5044)  (STFRI(JA,JB), JB = 1,KSYSM2)                  00001700
    7 CONTINUE                                                          00001710
C                                                                       00001720
  358 CONTINUE                                                          00001730
C                                                                       00001740
      WRITE(NUNIT,620)                                                  00001750
C                                                                       00001760
      DO 640  JA = 1,ISYS                                               00001770
```

```
      WRITE(NUNIT,1030) ( PHI(JA,JB), JB = 1,ISYS)                    00001780
  640 CONTINUE                                                        00001790
C                                                                     00001800
      WRITE(NUNIT,660)                                                00001810
      WRITE(NUNIT,1030) ( ELAM(JA), JA = 1,ISYS)                      00001820
C                                                                     00001830
C                                                                     00001840
  359 CONTINUE                                                        00001850
C                                                                     00001860
      IF(MPRINT .EQ. NO)  RETURN                                      00001870
C                                                                     00001880
      WRITE(6,1049)                                                   00001890
    2 WRITE(NUNIT,1050) C,ISYS,ISYS                                   00001900
C                                                                     00001910
C                                                                     00001920
      WRITE(NUNIT,1020)                                               00001930
      DO 40  JA = 1, ISYS                                             00001940
   40 WRITE(NUNIT,1030) ( BMIV(JA,JB), JB = 1, ISYS)                  00001950
C                                                                     00001960
      WRITE(NUNIT,5002)                                               00001970
      WRITE(NUNIT,1040)                                               00001980
      DO 50  JA = 1, ISYS                                             00001990
      WRITE(NUNIT,1030) ( DA(JA,JB), JB = 1, ISYS)                    00002000
   50 CONTINUE                                                        00002010
C                                                                     00002020
      WRITE(NUNIT,5002)                                               00002030
      WRITE(NUNIT,1060)                                               00002040
      DO 60  JA = 1, ISYS                                             00002050
      WRITE(NUNIT,1030) ( DV(JA,JB), JB = 1, ISYS)                    00002060
   60 CONTINUE                                                        00002070
C                                                                     00002080
   70 CONTINUE                                                        00002090
C                                                                     00002100
      RETURN                                                          00002110
      END                                                             00002120
```

```
      SUBROUTINE PRNTMX(COLM, COLC, COLK, SYSM, DAMP, STF, KSYS, C,      00000010
     1                  ISYS)                                            00000020
C                                                                        00000030
      IMPLICIT REAL*8(A-H,O-Z)                                           00000040
C                                                                        00000050
      INTEGER C                                                          00000060
C                                                                        00000070
      DIMENSION COLM(KSYS),   COLC(KSYS),   COLK(KSYS),                  00000080
     1          DAMP(KSYS,KSYS), STF(KSYS,KSYS), SYSM(KSYS,KSYS)         00000090
C                                                                        00000100
      COMMON NUNIT, IPRINT                                               00000110
C                                                                        00000120
      DATA  YES/4HYES /, NO/4HNO  /                                      00000130
C                                                                        00000140
 1030 FORMAT(' ',20X, 1P8D10.2)                                          00000150
 1031 FORMAT('0', 27X, 1PD10.2)                                          00000160
 1032 FORMAT('+', 47X, 1PD10.2)                                          00000170
 1033 FORMAT('+', 72X, 1PD10.2)                                          00000180
 1048 FORMAT('0',//////)                                                 00000190
 1049 FORMAT('1', //////)                                                00000200
 1050 FORMAT('0', 40X, ' CONFIGURATION AND MATRIX LAYER =', I3,//,50X,   00000210
     1   'MATRICES ARE',I3,'X',I1,//)                                    00000220
 1051 FORMAT('0', 40X, ' CONFIGURATION AND MATRIX LAYER =', I3,//,50X,   00000230
     1   'MATRICES ARE',I3,'X1',//)                                      00000240
 1070 FORMAT('0',//, 50X, '--- SYSM --- ',//)                            00000250
 1071 FORMAT('0',//,50X, ' --- DAMP ---',//)                             00000260
 1072 FORMAT('0',//,50X, ' --- STF ---',//)                              00000270
 1073 FORMAT('0', ///, 40X, 'COLUMN MATRICES FOR CALCULATION OF DELTA P' 00000280
     1            ,///, 32X, 'COLUMN MASS',  8X, 'COLUMN DAMPING',      00000290
     2               10X, 'COLUMN STIFFNESS' )                           00000300
C                                                                        00000310
C              ********************************************            00000320
C              **                                          **            00000330
C              **              PRINT  SYSTEM               **            00000340
C              **  MASS - DAMPING - STIFFNESS MATRICES     **            00000350
C              **       AND PRECALCULATED  MATRICES        **            00000360
C              **           COLM - COLC - COLK             **            00000370
C              **                                          **            00000380
C              ********************************************            00000390
C                                                                        00000400
      WRITE(6,1049)                                                      00000410
    2 WRITE(NUNIT,1050) C,ISYS,ISYS                                      00000420
      WRITE(NUNIT,1070)                                                  00000430
```

```
C                                                                       00000440
      DO  3  JA = 1,ISYS                                                00000450
      WRITE(NUNIT,1030) ( SYSM(JA,JB) ,  JB = 1,ISYS)                   00000460
    3 CONTINUE                                                          00000470
C                                                                       00000480
      WRITE(NUNIT,1071)                                                 00000490
      DO  4  JA = 1,ISYS                                                00000500
      WRITE(NUNIT,1030) ( DAMP(JA,JB) ,  JB = 1,ISYS)                   00000510
    4 CONTINUE                                                          00000520
C                                                                       00000530
      WRITE(NUNIT,1072)                                                 00000540
      DO  5  JA = 1,ISYS                                                00000550
      WRITE(NUNIT,1030) ( STF(JA,JB) ,  JB = 1,ISYS)                    00000560
    5 CONTINUE                                                          00000570
C                                                                       00000580
      WRITE(6,1049)                                                     00000590
      WRITE(6,1048)                                                     00000600
      WRITE(NUNIT,1051) C,ISYS                                          00000610
      WRITE(NUNIT,1073)                                                 00000620
C                                                                       00000630
      DO  6  JA = 1, ISYS                                               00000640
      WRITE(NUNIT,1031)  COLM(JA)                                       00000650
      WRITE(NUNIT,1032)  COLC(JA)                                       00000660
      WRITE(NUNIT,1033)  COLK(JA)                                       00000670
    6 CONTINUE                                                          00000680
C                                                                       00000690
      RETURN                                                            00000700
      END                                                               00000710
```

```
      SUBROUTINE  REDUCE( SYSM, DAMP, STF, KSYS)                                00000010
C                                                                               00000020
      IMPLICIT REAL*8(A-H,O-Z)                                                  00000030
C                                                                               00000040
      DIMENSION  SYSM(KSYS,KSYS,1), DAMP(KSYS,KSYS,1), STF(KSYS,KSYS,1)         00000050
C                                                                               00000060
      DO  10  JA =1,KSYS                                                        00000070
      DO  10  JB =1,KSYS                                                        00000080
      SYSM(JA,JB,3) = SYSM(JA,JB,1)                                             00000090
      DAMP(JA,JB,3) = DAMP(JA,JB,1)                                             00000100
      STF (JA,JB,3) = STF (JA,JB,1)                                             00000110
   10 CONTINUE                                                                  00000120
C                                                                               00000130
      DO  20  JC = 1,KSYS                                                       00000140
      SYSM(2,JC,3) = SYSM(2,JC,3) + SYSM(8,JC,3)                                00000150
      DAMP(2,JC,3) = DAMP(2,JC,3) + DAMP(8,JC,3)                                00000160
      STF (2,JC,3) = STF (2,JC,3) + STF (8,JC,3)                                00000170
   20 CONTINUE                                                                  00000180
C                                                                               00000190
      DO  30  JD = 1,KSYS                                                       00000200
      SYSM(JD,2,3) = SYSM(JD,2,3) + SYSM(JD,8,3)                                00000210
      DAMP(JD,2,3) = DAMP(JD,2,3) + DAMP(JD,8,3)                                00000220
      STF (JD,2,3) = STF (JD,2,3) + STF (JD,8,3)                                00000230
   30 CONTINUE                                                                  00000240
C                                                                               00000250
      RETURN                                                                    00000260
      END                                                                       00000270
```

```
      SUBROUTINE SHIFT( C, J, CONFIG, NPRINT)                          00000010
C                                                                      00000020
      INTEGER CONSAV, CSAVE, C, CONFIG, BINARY, YES                    00000030
C                                                                      00000040
      DIMENSION CONFIG(16,1)                                           00000050
C                                                                      00000060
      COMMON NUNIT, IPRINT                                             00000070
C                                                                      00000080
      DATA  YES/4HYES /, NO/4HNO  /                                    00000090
C                                                                      00000100
      BINARY(I3,I2,I1) = I3*4 + I2*2 + I1                              00000110
C                                                                      00000120
   10 FORMAT('0', 10X, 'FROM SHIFT, C=', I1,'  CONFIG(', I1,',', I1,   00000130
     1    ')=',I1)                                                    00000140
   11 FORMAT(' ', 10X, 'NEW C = ',I1)                                  00000150
C                                                                      00000160
      IF(NPRINT .EQ. NO)  GO TO 12                                     00000170
C                                                                      00000180
      WRITE(NUNIT,10) C,C,J,CONFIG(C,J)                                00000190
C                                                                      00000200
   12 CONSAV = CONFIG( C, J)                                           00000210
      CSAVE = C                                                        00000220
      CONFIG(C,J) = CONSAV + 1                                         00000230
C                                                                      00000240
      IF( CONFIG(C,J) .EQ. 2 )  CONFIG(C,J) = 0                        00000250
C                                                                      00000260
      C = BINARY( CONFIG(C,1), CONFIG(C,2), CONFIG(C,3) ) + 1          00000270
C                                                                      00000280
      IF(NPRINT .EQ. NO)   GO TO 20                                    00000290
C                                                                      00000300
      WRITE(NUNIT,11)  C                                               00000310
C                                                                      00000320
   20 CONFIG(CSAVE,J) = CONSAV                                         00000330
C                                                                      00000340
C                                                                      00000350
      RETURN                                                           00000360
      END                                                              00000370
```

```
      SUBROUTINE THESIS(FPLOT, DEG, DEG1, DEG2, NTIME, LINES, IP, GRID,  00000010
     1            Y1,Y2, Y3, Y4, YNAME, YNAME1, YNAME2, IGU, SCALE)      00000020
C                                                                        00000030
CC                                                                       00000040
C                                                                        00000050
      IMPLICIT REAL*8(A-H,O-Z)                                           00000060
C                                                                        00000070
      REAL*4 LABEL,TITLE,XNAME,YNAME1,YNAME2,YNAME,FPLOT,Y1,Y2,Y3,Y4,    00000080
     1       DEG, DEG1, DEG2, XSCALE(49)                                 00000090
      REAL*4 R4X, R4Y, QR4, WTR4, WNR4, RXZERO, RAMP, RRPM, RCLEAR       00000100
C                                                                        00000110
      INTEGER*2 GRID(LINES, 1)                                           00000120
C                                                                        00000130
      INTEGER YES,AGTOUT,DAMPNG,TAPE,CARDS,SEAT,C, PIN2$8                00000140
      INTEGER CONFIG(16,4), CSAVE, TWON, TWONP1                          00000150
C                                                                        00000160
      DIMENSION FPLOT(NTIME,1),  Y1(NTIME,1), Y2(NTIME,1), Y3(NTIME,1),  00000170
     1          Y4(NTIME,1), YNAME(20,1), YNAME1(20,1), YNAME2(20,1),    00000180
     2          DEG(1), DEG1(NTIME), DEG2(NTIME,1)                       00000190
      DIMENSION COLM(8,8), COLC(8,8), COLK(8,8), IDP(8,3), IQ(8,8)       00000200
      DIMENSION PHI(8,8,3), ELAM(8,3), IMPACT(3)                         00000210
      DIMENSION SYSM(8,8,8),STF(8,8,8),DAMP(8,8,8),                     00000220
     1          BMIV(8,8,9),  STFI(7,7),                                 00000230
     2          DA(8,8,9),DV(8,8,9),Q(10),QD(10),QDD(10),                00000240
     3          ALFA(8),BETA(8),STFRI(6,6),ICORD(3,2),                   00000250
     4          LABEL(20),TITLE(20),XNAME(20),DP(8),                     00000260
     7          QR4(10) , F(10), REALTH(4), AXILTH(4)                    00000270
      DIMENSION QSAV(10), QDSAV(10), QDDSAV(10), FSAV(10),               00000280
     1          DTP(3)                                                   00000290
      DIMENSION LAYER(8), IDIM(8)                                        00000300
C                                                                        00000310
CC                                                                       00000320
      COMMON NUNIT, IPRINT                                               00000330
C                                                                        00000340
      DATA CONFIG/64*0/                                                  00000350
      DATA YES/4HYES /, NO/4HNO  /                                       00000360
      DATA COLM/64*0.0D0/, COLC/64*0.0D0/, COLK/64*0.0D0/, IDP/24*0/     00000370
      DATA IQ/1,2,3,4,5,6,7,8, 1,2,3,4,5,6,8,0, 1,2,3,4,5,6,7,0,         00000380
     1     1,2,3,4,5,6,0,0, 2,3,4,5,6,7,8,0, 2,3,4,5,6,8,0,0,           00000390
     2     2,3,4,5,6,7,0,0, 2,3,4,5,6,0,0,0/                            00000400
      DATA LAYER/2*1, 2*3, 2*1, 2*3/                                     00000410
      DATA FSAV/8*0.0D0/                                                 00000420
      DATA LABEL(19)/'    '/, LABEL(20)/'    '/                          00000430
      DATA TITLE(19)/'    '/, TITLE(20)/'    '/                          00000440
      DATA XNAME(19)/'    '/, XNAME(20)/'    '/                          00000450
C                                                                        00000460
```

```
C                                                                       00000470
 5000 FORMAT('0','CONFIGURATION =',I3,5X,'DEGREES =',F9.3,10X,'WT =',   00000480
     1       1PD15.7)                                                   00000490
 5001 FORMAT('1')                                                       00000500
 5002 FORMAT('0', 10X, 'BACKSTEP ROUTINE CALLED DUE TO CHANGE IN ',     00000510
     1       ' CONFIGURATIONS')                                         00000520
 5003 FORMAT(' ', 10X, 'RETURNED TO MAIN FROM BACKSTEP ROUTINE')        00000530
 5004 FORMAT(' ', 10X, 'IN MAIN - LOCATION ',I4,' - - -   CSAVE=', I2,  00000540
     1       '  AND C =', I2)                                           00000550
 5005 FORMAT('0','    W=', 1PD15.7,'   AMPW=', D15.7,'   W2=', D15.7,   00000560
     1       '   AMPW2=', D15.7)                                        00000570
 5007 FORMAT('0', 10X, ' VALUES CALCULATED AFTER BACKSTEP TAKEN:')      00000580
 5015 FORMAT(5E10.4,2A4)                                                00000590
 5016 FORMAT('0', 10X, 'IMPACT FORCE AT COORDINATE ',I2, '=',1PD15.7,   00000600
     1       '- - - DEGREES ', 0PF9.3)                                  00000610
 5026 FORMAT('0',10X,20A4)                                              00000620
 5038 FORMAT(20A4)                                                      00000630
 5039 FORMAT('0',20X,20A4)                                              00000640
 5040 FORMAT('0',30X,20A4)                                              00000650
 5041 FORMAT(' ',5X,I5,5(10X,1PE10.3) )                                 00000660
 5050 FORMAT('0',40X,20A4)                                              00000670
 5051 FORMAT('0',50X,20A4)                                              00000680
 5062 FORMAT('0',23X,'DEGREES =',F9.3,10X,'WT =',1PD15.7)               00000690
 5063 FORMAT(' ','CAMQ =',1PD18.8, 10X,'CAMQD =', D18.8, 10X,'CAMQDD =',00000700
     1    D18.8)                                                        00000710
 5310 FORMAT('0',5(1PD15.7, 5X) )                                       00000720
C                                                                       00000730
CCC                                                                     00000740
CCC                                                                     00000750
CCC             ****************************************                00000760
CCC             **                                    **                00000770
CCC             **          READ INPUT VARIABLES      **                00000780
CCC             **                                    **                00000790
CCC             ****************************************                00000800
C                                                                       00000810
   50 CALL INPUT(LABEL, TITLE, XNAME, YNAME,                            00000820
     1           AGTOUT, CARDS, TAPE, IPLOT, IDRAW,                     00000830
     2           KPRINT, DAMPNG, RPM, CLEAR, WTDEG, AMP, DELT,          00000840
     3           ROCKER, AXILTH,                                        00000850
     4           REALTH, NTIME, KSYS, NCLEAR, NC,                       00000860
     5           NCOUNT, IDEG, PIN2$8, MPRINT)                          00000870
C                                                                       00000880
      FS = +145.0D0                                                     00000890
      PI = 3.1415926535890D0                                            00000900
      DEGR = 0.                                                         00000910
      WT = 0.                                                           00000920
      NDEG = 0                                                          00000930
      NDEGKP = 0                                                        00000940
```

```
      ICOUNT = 0                                                        00000950
      KAGT = 0                                                          00000960
      IAGT = 1                                                          00000970
      IDT = 0                                                           00000980
      IMP = 0                                                           00000990
      DTPM = 0.0D0                                                      00001000
      COFD = 1.0D0                                                      00001010
      IUNIT = 6                                                         00001020
      ICORD(1,1) = 1                                                    00001030
      ICORD(1,2) = 9                                                    00001040
      ICORD(2,1) = 2                                                    00001050
      ICORD(2,2) = 8                                                    00001060
      ICORD(3,1) = 7                                                    00001070
      ICORD(3,2) = 10                                                   00001080
      DT = DELT                                                         00001090
      NPRINT = IPRINT                                                   00001100
      SEAT = YES                                                        00001110
C                                                                       00001120
      NSYS = KSYS + 2                                                   00001130
      DEGOPI = 180.0D0/PI                                               00001140
      KSYSM1 = KSYS-1                                                   00001150
      KSYSM2 = KSYS-2                                                   00001160
      KSYSM3 = KSYS - 3                                                 00001170
      NCONF = NC                                                        00001180
      NCP1 = NC + 1                                                     00001190
C                                                                       00001200
      Q(10)      = CLEAR                                                00001210
      QD(10)     = 0.0D0                                                00001220
      QDD(10)    = 0.0D0                                                00001230
      QSAV(10)   = CLEAR                                                00001240
      QDSAV(10)  = 0.0D0                                                00001250
      QDDSAV(10)= 0.0D0                                                 00001260
      W = RPM*PI/30.0D0                                                 00001270
      AMPW = AMP*W                                                      00001280
      W2 = -W*W                                                         00001290
      AMPW2 = -AMPW*W                                                   00001300
      DTW = DT*W                                                        00001310
      WTSTOP = WTDEG    +15.0D0*DTW*DEGOPI                              00001320
      WTPRNT = WTDEG    - 3.0D0*DTW*DEGOPI                              00001330
C                                                                       00001340
      WRITE(NUNIT,5005) W, AMPW, W2, AMPW2                              00001350
      WRITE(NUNIT,5310) WTSTOP,WTPRNT,WTDEG, DTW, DEGOPI                00001360
      WRITE(NUNIT,5039) (LABEL(JA),JA=1,18)                             00001370
      WRITE(NUNIT,5039) (TITLE(JA),JA=1,18)                             00001380
C                                                                       00001390
      IF( TAPE  .EQ. YES)  IUNIT  =  4                                  00001400
      IF( CARDS .EQ. YES)  IUNIT  =  7                                  00001410
      IF(CLEAR .LE. -10.0)  SEAT = NO                                   00001420
```

```
      IF(DAMPNG .EQ. NO)  COFD = 0.0D0                                  00001430
C                                                                       00001440
CCCCC            ***************************************              00001450
CCCCC            **                                   **              00001460
CCCCC            **            CALL  MCK              **              00001470
CCCCC            **    SUBROUTINE MCK SETS UP THE SYSTEM **           00001480
CCCCC            **    MASS, DAMPING, AND STIFFNESS MATRICS **        00001490
CCCCC            **                                   **              00001500
CCCCC            ***************************************              00001510
C                                                                       00001520
      NE = 5                                                            00001530
   75 CALL MCK(SYSM,DAMP,STF,KSYS,8,NE,NPRINT,COFD,PHI,ELAM,1)          00001540
      IF(IGU .EQ. YES)  GO TO 78                                        00001550
C                                                                       00001560
      CALL MCK(SYSM,DAMP,STF,KSYS,7,NE,NPRINT,COFD,PHI,ELAM,3)          00001570
C                                                                       00001580
      GO TO 80                                                          00001590
   78 CALL REDUCE(SYSM,DAMP,STF,KSYS)                                   00001600
C                                                                       00001610
      DO 79  I = 1,KSYS                                                 00001620
      ELAM(I,3) = ELAM(I,1)                                             00001630
   79 CONTINUE                                                          00001640
C                                                                       00001650
CCCCC            ***************************************              00001660
CCCCC            **                                   **              00001670
CCCCC            **       ESTABLISH CONFIGURATION     **              00001680
CCCCC            **                MATRIX             **              00001690
CCCCC            **                                   **              00001700
CCCCC            ***************************************              00001710
C                                                                       00001720
   80 CALL CONMAT(NC, CONFIG, IDP, NPRINT, KSYS)                        00001730
C                                                                       00001740
CCCCC            ***************************************              00001750
CCCCC            **                                   **              00001760
CCCCC            **      ESTABLISH REDUCED MATRICS    **              00001770
CCCCC            **                                   **              00001780
CCCCC            ***************************************              00001790
C                                                                       00001800
      DO  100  C = 1,KSYS                                               00001810
      CALL MATRIX(COLM, COLC, COLK, SYSM, DAMP, STF, STFI, KSYS,        00001820
     1            KSYSM1, C, IQ, MPRINT, LAYER, IDIM)                   00001830
  100 CONTINUE                                                          00001840
C                                                                       00001850
C                                                                       00001860
  110 XZERO = FS*ROCKER*STFI(1,1)+AMP                                   00001870
      FZERO = XZERO/STFI(1,1)                                           00001880
      WN = ELAM(1,3)                                                    00001890
      IF(IGU .EQ. YES)  WN = ELAM(4,1)                                  00001900
```

```
C                                                                       00001910
CCCCCCCCC                                                               00001920
CCCCCCCCC          ****************************************             00001930
CCCCCCCCC          **                                    **             00001940
CCCCCCCCC          **  COMPUTE INITIAL PROGRAM PARAMETERS FOR **        00001950
CCCCCCCCC          **        CONTACT AT CAM AND ROCKER       **        00001960
CCCCCCCCC          **                                    **             00001970
CCCCCCCCC          ****************************************             00001980
C                                                                       00001990
  120 CALL INITAL(KSYS,Q,QD,QDD,AMPW,FS,FZERO,XZERO,ROCKER,KSYSM2,      00002000
     1            COLM(1,7),COLC(1,7),COLK(1,7),DP,F,DAMP(1,1,7),      00002010
     2            STF(1,1,7), STFRI, NPRINT)                           00002020
CCCCCCCCC                                                               00002030
CCCCCCCCC          ****************************************             00002040
CCCCCCCCC          **                                    **             00002050
CCCCCCCCC          **          CALL SUBROUTINE DEL       **             00002060
CCCCCCCCC          **  DEL ESTABLISHES MATRICS USED IN THE **           00002070
CCCCCCCCC          **  INTEGRATION ROUTINE. - - DEL SETS :  **          00002080
CCCCCCCCC          **     DELT/2,  DELT**2/3,  DELT**2/6    **          00002090
CCCCCCCCC          **              BMIVR, DAV, DVR           **          00002100
CCCCCCCCC          **                                    **             00002110
CCCCCCCCC          ****************************************             00002120
C                                                                       00002130
                                                                        00002140
      DO  180  C = 1,NCONF                                              00002150
CC                                                                      00002160
                                                                        00002170
      ISYS = IDIM(C)                                                    00002180
CC                                                                      00002190
                                                                        00002200
  183 CALL DEL(DT,DTO2,DT2O3,DT2O6,BMIV(1,1,C),DA(1,1,C),DV(1,1,C),     00002210
     1    SYSM(1,1,C), DAMP(1,1,C), STF(1,1,C), ISYS, C, NPRINT, KSYS,  00002220
     2    KPRINT)                                                       00002230
C                                                                       00002240
C                                                                       00002250
      IF(MPRINT .EQ. NO  .AND.  C .NE. 1)  GO TO 180                    00002260
      IC = 1                                                            00002270
      IF(C .EQ. 3  .AND.  IGU .EQ. NO)   IC = 3                         00002280
           CALL PRINT(KSYS, ISYS, C, SYSM(1,1,C), DAMP(1,1,C),          00002290
     2          STF(1,1,C), BMIV(1,1,C), DA(1,1,C), DV(1,1,C), CONFIG  00002300
     2          (1,2), PHI(1,1,IC), ELAM(1,IC), STFI, STFRI, WTSTOP,   00002310
     3          WTPRNT, LABEL, YNAME, XNAME, TITLE,                    00002320
     4          AGTOUT, CARDS, TAPE, IPLOT, IDRAW, DAMPNG, RPM, CLEAR, 00002330
     5          AMP, DELT, ROCKER, AXILTH, REALTH, NTIME, NC,          00002340
     6          NCLEAR, KSYSM1, COLM, COLC, COLK, COFD, ICORD,         00002350
     7          LAYER, IDP, IQ, IDIM, KSYSM2, PIN2$8, XZERO, FZERO,    00002360
     8          MPRINT)                                                00002370
C                                                                       00002380
```

```
C                                                                       00002390
C                                                                       00002400
  180 CONTINUE                                                          00002410
C                                                                       00002420
      WRITE(NUNIT,5001)                                                 00002430
C                                                                       00002440
C     INITIAL CONTACT AT CAM AND ROCKER                                 00002450
  190 C = 7                                                             00002460
      CSAVE = C + 1                                                     00002470
C                                                                       00002480
C               ********************************************            00002490
C               **                                        **            00002500
C               **          CONVERT TO REAL * 4           **            00002510
C               **          OUTPUT FOR AGT                **            00002520
C               **                                        **            00002530
C               ********************************************            00002540
C                                                                       00002550
      IF( AGTOUT .EQ. NO ) GO TO  265                                   00002560
      RXZERO  =  XZERO                                                  00002570
      RAMP  =  AMP                                                      00002580
      RRPM  =  RPM                                                      00002590
      RCLEAR = CLEAR                                                    00002600
      WNR4 = WN                                                         00002610
C                                                                       00002620
      IF(IUNIT .EQ. 6)  GO TO 260                                       00002630
      WRITE(IUNIT, 5038) (LABEL(JA),JA=1,18)                            00002640
      WRITE(IUNIT, 5038) (TITLE(JA),JA=1,18)                            00002650
C                                                                       00002660
  260 WRITE(IUNIT,5015) RXZERO,RAMP,RRPM, WNR4, RCLEAR, SEAT, PIN2$8    00002670
  265 CONTINUE                                                          00002680
C                                                                       00002690
C-----------------------------------------------------------------------00002700
C********************** CONFIGURATION CALCULATIONS ********************00002710
C-----------------------------------------------------------------------00002720
C                                                                       00002730
C               ********************************************            00002740
C               **                                        **            00002750
C               **          INITIALIZING ROUTINE          **            00002760
C               **                                        **            00002770
C               ********************************************            00002780
C                                                                       00002790
  360 WT = WT + DTW                                                     00002800
C                                                                       00002810
      DO 361  JA = 1, NSYS                                              00002820
      CALL ADJUST(JA,JA,QSAV,QDSAV,QDDSAV,Q,QD,QDD)                     00002830
  361 CONTINUE                                                          00002840
C                                                                       00002850
      DO 364  I = 1, KSYS                                               00002860
```

```
      FSAV(I) = F(I)                                                    00002870
      FSAV(I) = DABS(F(I))                                              00002880
  364 CONTINUE                                                          00002890
C                                                                       00002900
      IF(DEGR .GT.WTPRNT)   NPRINT = YES                                00002910
      IF(DEGR .GT.WTSTOP)   STOP                                        00002920
C                                                                       00002930
  365 CALL CAM(WT,AMP,AMPW,XZERO,W2,Q,QD,QDD)                           00002940
C                                                                       00002950
      IF(C .NE. CSAVE .AND. NPRINT .EQ. YES) WRITE(NUNIT,5000) C,DEGR,WT00002960
      IF(C .EQ. CSAVE .AND. NPRINT .EQ. YES)  WRITE(NUNIT,5062) DEGR,WT 00002970
C                                                                       00002980
C                                                                       00002990
      CALL BRANCH(C,F,KSYS,ISYS,Q,QD,QDD,QDSAV,ICORD,DT,NPRINT,         00003000
     1            NCLEAR, IMP, PIN2$8, IDIM)                            00003010
C                                                                       00003020
C                                                                       00003030
  390 CALL NEWMRK( ISYS, KSYS,     C,     STF , DAMP, SYSM, DP,         00003040
     1  DT, DTO2, DT206, DT203, Q, QD, QDD, BMIV(1,1,C), DA(1,1,C),     00003050
     2  DV(1,1,C),NC,ALFA,BETA,CONFIG(1,2),F,ICORD,NCLEAR,NPRINT,IQ,    00003060
     3  COLM, COLC, COLK, IDP, PIN2$8, IDIM, LAYER, IGU, QDDSAV,        00003070
     4  QDSAV, QSAV, SCALE, IMP)                                        00003080
C                                                                       00003090
      IF(((KPRINT .EQ. YES) .OR. (NPRINT .EQ. YES)).AND. (IMP .NE. 0))  00003100
     1            WRITE(NUNIT,5016) IMP, F(IMP), DEGR                   00003110
C                                                                       00003120
C                                                                       00003130
      IF(NPRINT .EQ. YES)  CALL DEBUG( 2, Q, QD, QDD, F, KSYS, ISYS, DP,00003140
     1                                 NDEG, NPRINT, DEGR, C)           00003150
C                                                                       00003160
C                                                                       00003170
C                                                                       00003180
  400 CSAVE = C                                                         00003190
  405 IF(NDEG .LT. IDEG)  GO TO 463                                     00003200
C                                                                       00003210
C             **********************************************            00003220
C             **                                          **            00003230
C             **              CHECK TO SEE IF             **            00003240
C             **         MONITORED VALUES  HAVE BEEN      **            00003250
C             **      EXCEEDED AND IF SO SHIFT TO THE     **            00003260
C             **         APPROPRIATE CONFIGURATION        **            00003270
C             **                                          **            00003280
C             **********************************************            00003290
C                                                                       00003300
  410 CALL MONTOR(NCLEAR, CONFIG(1,2), ICORD, F, C, NPRINT, IDT, DTP,   00003310
     1            DTPM, IMPACT, Q, QSAV, FSAV, DT)                      00003320
C                                                                       00003330
```

```
C               ********************************************                    00003340
CC              **                                          **                    00003350
CC              **  DETERMINE IF IMPACT AND AT WHAT COORD.  **                    00003360
CC              **                                          **                    00003370
CC              ********************************************                    00003380
C                                                                               00003390
      DO 415  IMP = 1,NCLEAR                                                    00003400
      IF(IDT .EQ. IMPACT(IMP) )  GO TO 418                                      00003410
  415 CONTINUE                                                                  00003420
      IMP = 0                                                                   00003430
      GO TO 420                                                                 00003440
C                                                                               00003450
  418 IMP = ICORD(IMP,1)                                                        00003460
  420 IF(CSAVE .EQ. C )  GO TO 450                                              00003470
C                                                                               00003480
      IF(NPRINT .EQ. YES)  WRITE(NUNIT,5002)                                    00003490
C                                                                               00003500
  440 CALL BKSTEP( BMIV(1,1,NCP1), DA(1,1,NCP1), DV(1,1,NCP1), W, WT,           00003510
     1            SYSM, DAMP, STF, CSAVE, NPRINT, KSYS, KPRINT,                00003520
     2            DP, Q,QD, QDD,    ALFA, BETA, CONFIG(1,2), F,                00003530
     3            ICORD, NCLEAR, AMP, XZERO, DTPM,  DT, ISYS, NC, AMPW,        00003540
     4            W2, KSYSM1, KSYSM2, DTW, NSYS, IDT, PIN2$8, IDIM, IQ,        00003550
     5            COLM, COLC, COLK, IDP, QSAV, QDSAV, QDDSAV, FSAV,            00003560
     6            LAYER, C, IGU, SCALE)                                        00003570
      IF(NPRINT .EQ. YES)  WRITE(NUNIT,5003)                                    00003580
C               ********************************************                    00003590
CC              **                                          **                    00003600
CC              **  PROGRAM PARAMETERS ARE NOW CALCULATED   **                    00003610
CC              **       ESTABLISH PLOT PACKAGE             **                    00003620
CC              **                                          **                    00003630
CC              ********************************************                    00003640
C                                                                               00003650
  450 CALL FIXFOR(CSAVE, F)                                                     00003660
      GO TO 465                                                                 00003670
C                                                                               00003680
  463 DO 464  I = 1, KSYS                                                       00003690
      FSAV(I) = DABS(F(I))                                                      00003700
  464 CONTINUE                                                                  00003710
  465 IF(DEGR .EQ. 0.0)  CALL DEBUG(2,Q,QD,QDD,F, KSYS, ISYS, DP, NDEG,         00003720
     1                              NPRINT, DEGR, C)                           00003730
C                                                                               00003740
      DEGR = WT*DEGOPI                                                          00003750
      NDEGKP = NDEG                                                             00003760
      NDEG = DEGR                                                               00003770
C                                                                               00003780
      IF( NDEG .EQ. NDEGKP )  GO TO  360                                        00003790
```

```
C                                                                       00003810
  533 DEG( NDEG )  =  DEGR                                              00003820
      INTIME = NDEG + NTIME                                             00003830
      DEG(INTIME) = DEGR                                                00003840
C                                                                       00003850
      IF( AGTOUT .EQ. NO ) GO TO  535                                   00003860
C                                                                       00003870
      IF( NDEG .LT. 360 .OR. NDEG .GT. 725 )   GO  TO  535              00003880
      IAGT = IAGT + 1                                                   00003890
      IF(IAGT .LT. 2)  GO TO 535                                        00003900
      IAGT = 0                                                          00003910
      KAGT = KAGT + 1                                                   00003920
C                                                                       00003930
      CALL AGT(Q, QR4, WT, WTR4, XZERO, ROCKER, NPRINT, AXILTH,         00003940
     2         REALTH, C, IUNIT, KAGT)                                  00003950
  535 CONTINUE                                                          00003960
C                                                                       00003970
      CALL ARRAY(F, Q, QD, QDD, NDEG, FPLOT, NTIME)                     00003980
C                                                                       00003990
      IF(KPRINT .EQ. NO )  GO TO  634                                   00004000
C                                                                       00004010
      ICOUNT = ICOUNT + 1                                               00004020
      IF(ICOUNT .LT. NCOUNT)  GO TO  634                                00004030
      ICOUNT = 0                                                        00004040
C                                                                       00004050
      CALL DEBUG( 2, Q, QD, QDD, F, KSYS, ISYS, DP, NDEG, NPRINT, DEGR, 00004060
     1            C)                                                    00004070
  634 CONTINUE                                                          00004080
C                                                                       00004090
  636 IF( NDEG .LT. NTIME) GO TO 360                                    00004100
C                                                                       00004110
CCCCC               ******************************************          00004120
CCCCC               **                                      **          00004130
CCCCC               **   PLOT PACKAGE FOR SPECIFIED GRAPHS  **          00004140
CCCCC               **                                      **          00004150
CCCCC               ******************************************          00004160
C                                                                       00004170
      CALL GRAPH(FPLOT, YNAME, XNAME, DEG1, DEG2, Y1, Y2, Y3, Y4,       00004180
     1           YNAME1, YNAME2, PIN2$8, CLEAR,                         00004190
     2           NTIME, LABEL, TITLE, IDRAW, IPLOT, XSCALE,             00004200
     3           IP, NPRINT, GRID, LINES)                               00004210
C                                                                       00004220
      GO TO 50                                                          00004230
 4037 RETURN                                                            00004240
      END                                                               00004250
```

SDS-9300 COMPUTER PROGRAM LISTING

This listing is coded in SDS FORTRAN IV, (Ref. 5-7), to run on a Scientific Data System Mode 9300 computer interfaced with an ADAGE Graphics Display Terminal, Model 10 (AGT-10). Due to the limited core storage of this computer, overlaying techniques have been employed.

```
C     SENSE SWITCH 1 - - RESTART - - READ                                    00000010
C     SENSE SWITCH 2 - - INPUT(101)                                          00000020
C     SENSE SWITCH 3 - - CALL CAM                                            00000030
C     SENSE SWITCH 5 - - CALL JOINT                                          00000040
C     SENSE SWITCH 6 - - IF MOD EACH CYCLE                                   00000050
      INTEGER YES, BLNK, PIN28                                               00000060
      INTEGER ROTATE, CONFIG                                                 00000070
      DIMENSION IRRAY1( 97),IRRAY2( 18),IRRAY3(13),IRRAY4(32)                00000080
      DIMENSION IRRAY5(24), IRRAY6(36),IRRAY7(24),ISPRNG(9),IRRAY9( 49)      00000090
      DIMENSION IRRAY10( 49), I101(7), I105(3), I104(8), I117(5)             00000100
      DIMENSION I106(12), I107(11), I108( 7), I109( 7), I110(2)              00000110
      DIMENSION I111( 5), I112( 9), I113(8), I114(11), I115(1), I116(10)     00000120
      DIMENSION X(9), Y(9), CONFIG(180), YZERO(9)                            00000130
      DIMENSION RADCOS(97), RADSIN(97)                                       00000140
      COMMON AXLTH1, AXLTH2, AXLTH3, AXLTH4                                  00000150
      COMMON WTH1, WTH2, WTH3, WTH4                                          00000160
      COMMON PI, RAD, DEG, IDEV                                              00000170
      COMMON IGDIR(20), ITDIR(40)                                            00000180
      COMMON XA,YA,XB,YB,XC,YC,XD,YD,XE,YE,XF,YF,XG,YG,XH,YH,XS,YS,XP,YP     00000190
      COMMON Q1(180),Q2(180),Q3(180),Q4(180),Q5(180),Q6(180),Q7(180)         00000200
      COMMON Q8(180),Q9(180),OMEGA(180)                                      00000210
      COMMON XCAM , YCAM                                                     00000220
      DATA NULL/77777777B/, BLNK/4H    /, YES/4HYES /, NO/4HNO  /            00000230
      DATA PIN28/28/                                                         00000240
  102 FORMAT(1PE12.2,28X)                                                    00000250
  103 FORMAT('FREQ. RATIO                    ')                              00000260
 1430 FORMAT('CONTACT AT :                   ')                              00000270
 1431 FORMAT('CAM                            ')                              00000280
 1432 FORMAT('ROCKER                         ')                              00000290
 1433 FORMAT('NO  CONTACT ')                                                 00000300
 1434 FORMAT('VALVE SEAT          ')                                         00000310
 1450 FORMAT('CAM ROTATION        ')                                         00000320
 1455 FORMAT('DEGREES ')                                                     00000330
 1460 FORMAT('CONFIGURATION                  ')                              00000340
 1550 FORMAT(I3,1X)                                                          00000350
      NAMELIST CONFIG, ISEAT, SF1, SF2, SF3, SF4, SF1A, SF4A, WN, XZERO,    00000360
     1  AMP, RPM, IER, RADIUS, DTHETA, FREQ, AXLTH1, AXLTH2, AXLTH3,        00000370
     2  AXLTH4, WTH1, WTH2, WTH3, WTH4, IDEV, XA, XB, XC, XD, XE, XF,       00000380
     3  XG, XH, XS, XP, XCAM, YA, YB, YC, YD, YE, YF, YG, YH, YS, YP,       00000390
     4  YCAM, DIFF                                                          00000400
      CMTOGD(A) = A / 0.2000  +  5.000                                       00000410
      GDTOCM(A) = 0.2000*A - 1.0000                                          00000420
      IDEV = 1                                                               00000430
    1 CONTINUE                                                               00000440
      PI = 3.14159265                                                        00000450
      TWOPI = 2.0*PI                                                         00000460
      NTIME = 180                                                            00000470
      ISEAT = YES                                                            00000480
      DEG = 180.0/PI
```

```
      RAD = PI/180.0                                                          00000490
      SF1  = 1.0                                                              00000500
      SF2  = 1.0                                                              00000510
      SF3  = 1.0                                                              00000520
      SF4  = 1.0                                                              00000530
      SF1A = 15.0                                                             00000540
      SF4A = 15.0                                                             00000550
      WTH1=WTH2=WTH3=WTH4=0.4                                                 00000560
      AXLTH1 = 7.9                                                            00000570
      AXLTH2 = 3.4                                                            00000580
      AXLTH3 = 5.1                                                            00000590
      AXLTH4 = 3.3                                                            00000600
      XA = 0.5    ;    YA =-0.5                                               00000610
      XB = 3.9    ;    YB = 9.3                                               00000620
      XC = 10.2   ;    YC = 7.3                                               00000630
      XD = 0.5    ;    YD = 9.1                                               00000640
      XE = 1.0    ;    YE =-0.6                                               00000650
      XF = 0.5    ;    YF = 9.3                                               00000660
      XG = 3.9    ;    YG = 9.1                                               00000670
      XH = 9.0    ;    YH = 9.1                                               00000680
      XP =11.2    ;    YP = -0.02                                             00000690
      XS = 6.8    ;    YS = -0.02                                             00000700
      CALL INITAL(CONFIG, IRRAY1,                                             00000710
     1            IRRAY2,IRRAY3,IRRAY4,IRRAY5,IRRAY6,IRRAY7,IRRAY9,          00000720
     2            IRRAY10,ISPRING)                                           00000730
      CALL READ(NTIME, I104, I105, XZERO, AMP, RPM, WN, ISEAT, PIN28,         00000740
     1          CONFIG, DIFF)                                                 00000750
      THETA = 0.0                                                             00000760
      RADIUS = 1.5                                                            00000770
      DTHETA= 4.0*RAD                                                         00000780
      IF(SENSE SWITCH 2 ) 2, 1260                                             00000790
    2 OUTPUT(101) ' INPUT  CHANGES' ;  INPUT(101)                             00000800
 1260 CONTINUE                                                                00000810
X     OUTPUT(6) ' SPRCTR CALLED '                                             00000820
      CALL SPRCTR(IRRAY3,ISEAT, DIFF)                                         00000830
      CALL MIDBAR(IRRAY2,IRRAY9)                                              00000840
      DO  1400  I = 6, 97                                                     00000850
      THETA = THETA + DTHETA                                                  00000860
      RADCOS(I) = RADIUS*COS(THETA)                                           00000870
      RADSIN(I) = RADIUS*SIN(THETA)                                           00000880
 1400 CONTINUE                                                                00000890
      AMP02 = AMP/2.0                                                         00000900
      FREQ = ( RPM * PI ) / ( WN * 30.0 )                                     00000910
      ENCODE(40,102,I116) FREQ                                                00000920
      ENCODE(32,103,I113)                                                     00000930
      ENCODE(20,1450,I111)                                                    00000940
      ENCODE(8,1455,I110)                                                     00000950
      ENCODE(28,1430,I109)                                                    00000960
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      ENCODE(32,1431,I104)                                                    00000970
      ENCODE(28,1432,I101)                                                    00000980
      ENCODE(12,1433,I105)                                                    00000990
      ENCODE(20,1434,I117)                                                    00001000
      ENCODE(28,1460,I108)                                                    00001010
      CALL TEXTO(IDEV,I108, 7,24,30,2,3,IER)                                  00001020
      IF(IER.NE.0) OUTPUT(101) IER                                            00001030
      CALL TEXTO(IDEV,I113,8,38,71,2,3,IER)                                   00001040
      IF(IER.NE.0) OUTPUT(101) IER                                            00001050
      CALL TEXTO(IDEV,I116,10,40,65,2,3,IER)                                  00001060
      IF(IER.NE.0) OUTPUT(101) IER                                            00001070
      CALL TEXTO(IDEV,I110,2,40,44,2,3,IER)                                   00001080
      IF(IER.NE.0) OUTPUT(101) IER                                            00001090
      CALL TEXTO(IDEV,I111,5,38,36,2,3,IER)                                   00001100
      IF(IER.NE.0) OUTPUT(101) IER                                            00001110
      N = 0    ;  I = 0                                                       00001120
 1500 DO  2000  K = 1, NTIME                                                  00001130
      I = I +1                                                                00001140
      IF( K .EQ. NTIME)  OUTPUT(6) '          COMPLETE CYCLE'                 00001150
      N = N +1                                                                00001160
      CALL DISPLY(CONFIG, K, I105, I109, I117, I101,I104)                     00001170
X     OUTPUT(6) ' CAM CALLED '                                                00001180
      IF( SENSE SWITCH 3 ) 3, 1551                                            00001190
    3 CALL CAM( 97, IRRAY1,RADIUS,AMP,I,RADCOS,RADSIN)                        00001200
 1551 ROTATE = IFIX(   OMEGA(I) * DEG )                                       00001210
      ENCODE(4,1550,I115) ROTATE                                              00001220
      CALL TEXTO(IDEV,NULL,1,40,36,2,3,IER)                                   00001230
      IF(IER.NE.0) OUTPUT(101) IER                                            00001240
      CALL TEXTO(IDEV,I115,1,40,36,2,3,IER)                                   00001250
      IF(IER.NE.0) OUTPUT(101) IER                                            00001260
 1600 CALL BAR1( I,IRRAY4,SF1,SF1A,PIN28)                                     00001270
      CALL BAR2( I,IRRAY5,SF2,IRRAY9,PIN28)                                   00001280
      CALL BAR3( I,IRRAY6,SF3,IRRAY10)                                        00001290
      CALL BAR4( I,IRRAY7,SF4,SF4A)                                           00001300
      IF(  I .NE. 1 )  GO TO 175                                              00001310
      X(1) = Y(1) = 0.0                                                       00001320
      X(2) = XC   ;  Y(2) = YC                                                00001330
      X(3) = X(5) = X(7) = XH - 0.6                                           00001340
      X(4) = X(6) = XH + 0.6                                                  00001350
      X(8) = XH                                                               00001360
      DO  50  J = 1, 5                                                        00001370
      Y(J+2) = FLOAT(J)*(YH-YC)/6.0 + YC                                      00001380
   50 CONTINUE                                                                00001390
      Y(8) = YH                                                               00001400
      X(9) = Y(9) = 0.0                                                       00001410
      ISPRNG(1) = IHEAD(0,10)                                                 00001420
      DO  100  J = 1, 9                                                       00001430
      YZERO(J) = Y(J)                                                         00001440
```

```
      X(J) = GDTOCM( X(J) )  ;  Y(J) = GDTOCM( Y(J) )                    00001450
      CONTINUE                                                           00001460
  100 ISPRNG(2) = IPACK( X(2), Y(2), 0)                                  00001470
      DO   150  J = 3,8                                                  00001480
      ISPRNG(J) = IPACK( X(J), Y(J), 1 )                                 00001490
      CONTINUE                                                           00001500
  150 ISPRNG(9) = 0                                                      00001510
      CALL GRAPHO(IDEV,ISPRNG,9,8,IER)                                   00001520
      IF(IER.NE.0) OUTPUT(101) IER                                       00001530
      IF(  I .EQ. 1 )  GO TO 1990                                        00001540
      CONTINUE                                                           00001550
  175 DO 200  J  = 3, 8                                                  00001560
      Y(J) = CMTOGD( Y(J) )                                              00001570
      Y(J) = YZERO(J) + FLOAT(J-2) * Q4( I)*SF4/ 6.0                     00001580
      Y(J) = GDTOCM( Y(J) )                                              00001590
      ISPRNG(J) = IPACK( X(J), Y(J), 1 )                                 00001600
      CONTINUE                                                           00001610
  200 CALL GRAPHO(IDEV,ISPRNG,9,8,IER)                                   00001620
      IF(IER.NE.0) OUTPUT(101) IER                                       00001630
      CONTINUE                                                           00001640
 1990 IF( SENSE SWITCH 1 ) 1, 1991                                       00001650
      CONTINUE                                                           00001660
 1991 IF( SENSE SWITCH 2) 2,1992                                         00001670
      CONTINUE                                                           00001680
 1992 IF( SENSE SWITCH 6 ) 6, 2000                                       00001690
      CALL TEXTR(IDEV,NULL,1,39,46,2,3,IER)                              00001700
    6 IF(IER.NE.0) OUTPUT(101) IER                                       00001710
      IF(MOD(ITDIR(1),8).EQ.0)  GO TO 1998                               00001720
 1998 CONTINUE                                                           00001730
 2000 I = 1  ;  N = 1                                                    00001740
      GO TO 1500                                                         00001750
      END                                                                00001760
```

```
      SUBROUTINE BAR1(JA,LINK1,SF1,SF1A,PIN28)                          00000010
      INTEGER PIN28, YES                                                00000020
      DIMENSION LINK1(32), X(31), Y(31), AMP(8)                         00000030
      COMMON AXLTH1, AXLTH2, AXLTH3, AXLTH4                             00000040
      COMMON WTH1, WTH2, WTH3, WTH4                                     00000050
      COMMON PI, RAD, DEG, IDEV                                         00000060
      COMMON IGDIR(20), ITDIR(40)                                       00000070
      COMMON XA,YA,XB,YB,XC,YC,XD,YD,XE,YE,XF,YF,XG,YG,XH,YH,XS,YS,XP,YP00000080
      COMMON Q1(180),Q2(180),Q3(180),Q4(180),Q5(180),Q6(180),Q7(180)    00000090
      COMMON Q8(180),Q9(180),OMEGA(180)                                 00000100
      COMMON XCAM , YCAM                                                00000110
      DATA YES/4HYES /, NO/4HNO  /                                      00000120
      CMTOGD(A) = A / 0.2000  +  5.000                                  00000130
      GDTOCM(A) = 0.2000*A - 1.0000                                     00000140
      NAMELIST IER                                                      00000150
      LINK1(1) = IHEAD(0,10)                                            00000160
      IF( JA .NE. 1 )  GO TO 500                                        00000170
      X(2) = XD    ;    Y(2) = YD                                       00000180
      X(31) = X(2)    ;   Y(31) = Y(2)                                  00000190
      Y(3) = Y(30) = Y(2) - 0.2                                         00000200
      YZERO3 = Y(3)                                                     00000210
      DO  30  I = 3, 14                                                 00000220
      Y(I) = Y(33-I) = Y(3) - FLOAT(I-3) * AXLTH1 / 11.0                00000230
      X(I) = X(2) - WTH1/2.0                                            00000240
      X(33-I) = X(3) + WTH1                                             00000250
   30 CONTINUE                                                          00000260
      X(15) = X(16) = X(2) - 3*WTH1                                     00000270
      X(17) = X(18)  =  X(2) + 3*WTH1                                   00000280
      X(30) = X(19)                                                     00000290
      Y(15) = Y(18) =Y(19) = Y(14)                                      00000300
      Y(16) = Y(17) = Y(14) - WTH1                                      00000310
      YZER14 = Y(14)                                                    00000320
      DO   45  I = 2,31                                                 00000330
      X(I) = GDTOCM( X(I) )  ;  Y(I) = GDTOCM( Y(I) )                   00000340
   45 CONTINUE                                                          00000350
   49 DO 50  I = 2,31                                                   00000360
      IF( I .EQ. 2)  LINK1(2) = IPACK( X(2), Y(2), 0 )  ;  GO TO 50     00000370
      LINK1(I) = IPACK( X(I), Y(I), 1 )                                 00000380
   50 CONTINUE                                                          00000390
      LINK1(32) = 0                                                     00000400
      CALL GRAPHO( IDEV, LINK1, 32,4,IER )                              00000410
      IF(IER.NE.0) OUTPUT(101) IER,'BAR1-1'                             00000420
   99 FORMAT(' ',3X,'I=',I3,2E15.4)                                     00000430
      IF( JA .EQ. 1 )  RETURN                                           00000440
  500 DO  550  I = 2,31                                                 00000450
      X(I) = CMTOGD( X(I) )    ;  Y(I) = CMTOGD( Y(I) )                 00000460
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550 CONTINUE                                                          00000470
    IF(PIN28.EQ.YES)   Y(3) = Y(30) = YZERO3 + Q2(JA)*SF1             00000480
    IF(PIN28.EQ.NO)    Y(3) = Y(30) = YZERO3 + Q8(JA)*SF1 + YP        00000490
    Y(2) = Y(3) + 0.2                                                 00000500
    Y(31) = Y(2)                                                      00000510
    Y(14) = Y(15) = Y(18) = Y(19) = YZER14  + Q1(JA)*SF1              00000520
    Y(16) = Y(17) = Y(14) - WTH1                                      00000530
    DIFF = ABS( Y(3) - Y(14) ) - AXLTH1                               00000540
    DO  560  I = 4, 13                                                00000550
    Y(I) = Y(33-I)=Y(3)- ( FLOAT(I-3) * (Y(3)-Y(14))/ 11.0 )          00000560
560 CONTINUE                                                          00000570
    DO  575  I = 4, 8                                                 00000580
    AMP(I) = DIFF*SIN( FLOAT(I-3) * PI/11.0 ) * SF1A                  00000590
    IF( AMP(I) .GT. WTH1/2.0 )    AMP(I) = WTH1/2.0                   00000600
 98 FORMAT(' ', 3X, 'I= ',I3, '    AMP= ' , E15.5)                    00000610
    X(I) = X(17-I) = X(3) + AMP(I)                                    00000620
    X(33-I) = X(I+16) = X(I) + WTH1 - 2.0*AMP(I)                      00000630
575 CONTINUE                                                          00000640
    DO  600  I = 2,31                                                 00000650
    X(I) = GDTOCM( X(I) )  ;  Y(I) = GDTOCM( Y(I) )                   00000660
    LINK1(I) = IPACK( X(I), Y(I), 1 )                                 00000670
600 CONTINUE                                                          00000680
    LINK1(2) = IPACK( X(2), Y(2), 0 )                                 00000690
    LINK1(32) = 0                                                     00000700
    CALL GRAPHO( IDEV, LINK1, 32,4,IER )                              00000710
    IF(IER.NE.0) OUTPUT(101) IER,'BAR1-2'                             00000720
    RETURN                                                            00000730
    END                                                               00000740
```

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      SUBROUTINE BAR2(JA,LINK2,SF2,IRRAY9,PIN28)                        00000010
      INTEGER PIN28, YES                                                00000020
      DIMENSION LINK2(24), X(24), Y(24), PHI(10,3), YZERO(24)           00000030
      COMMON AXLTH1, AXLTH2, AXLTH3, AXLTH4                             00000040
      COMMON WTH1, WTH2, WTH3, WTH4                                     00000050
      COMMON PI, RAD, DEG, IDEV                                         00000060
      COMMON IGDIR(20), ITDIR(40)                                       00000070
      COMMON XA,YA,XB,YB,XC,YC,XD,YD,XE,YE,XF,YF,XG,YG,XH,YH,XS,YS,XP,YP00000080
      COMMON Q1(180),Q2(180),Q3(180),Q4(180),Q5(180),Q6(180),Q7(180)    00000090
      COMMON Q8(180),Q9(180),OMEGA(180)                                 00000100
      COMMON XCAM , YCAM                                                00000110
      DATA YES/4HYES /, NO/4HNO  /                                      00000120
      GDTOCM(A) = 0.2000*A - 1.0000                                     00000130
      CMTOGD(A) = A / 0.2000  +  5.000                                  00000140
      NAMELIST IER                                                      00000150
      L = 1                                                             00000160
      K = 2                                                             00000170
      IF( JA .NE. 1 )  GO TO 200                                        00000180
      X(1) = Y(1) = 0.0                                                 00000190
      X(24) = XF    ;  Y(24) = YF                                       00000200
      FACT2 =  Y(24) - WTH2/2.0                                         00000210
      FACT3 =  Y(24) + WTH2/2.0                                         00000220
      DO  10  I = 2,12                                                  00000230
      Y(I) = YZERO(I) = FACT2                                           00000240
      Y(I+11) = FACT3                                                   00000250
   10 CONTINUE                                                          00000260
      DO  25  I = 1, 11                                                 00000270
      X(13-I) = X(12+I) = X(24) + FLOAT(I-1) * AXLTH2 / 10.0            00000280
   25 CONTINUE                                                          00000290
      XA = X(12)          ;   YA = Y(12)                                00000300
      IF(PIN28 .EQ. NO)  GO TO 26                                       00000310
      IF( SENSE SWITCH 5 ) 5,26                                         00000320
    5 CALL JOINT( 37, IRRAY9, 0.1 ,10.0, K, JA)                         00000330
   26 CONTINUE                                                          00000340
      AL22 = AXLTH2**2                                                  00000350
      AL23 = AXLTH2**3                                                  00000360
      DO  30  I = 3, 12                                                 00000370
      XX = X(I) - X(24)                                                 00000380
      XX2 = XX**2                                                       00000390
      XX3 = XX2 * XX                                                    00000400
      PHI(I-2,1  ) = (AL23 - 3.0*XX2*AXLTH2 + 2.0*XX3 ) * SF2/AL23      00000410
      PHI(I-2,3-L) = (XX*AL22 - 2.0*XX2*AXLTH2 + XX3 ) * SF2/AL22       00000420
      PHI(I-2,4-L) = -( XX2*AXLTH2 - XX3 ) * SF2/AL22                   00000430
   30 CONTINUE                                                          00000440
      DO  50  I = 1, 23                                                 00000450
   99 FORMAT(' ',3X,'I=',I3,2E15.4)                                     00000460
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```
      X(I) = GDTOCM( X(I) )  ;  Y(I) = GDTOCM( Y(I) )                                                    00000470
   50 CONTINUE                                                                                           00000480
      LINK2(1) = IHEAD(0,10)                                                                             00000490
      LINK2(2) = IPACK( X(2), Y(2), 0 )                                                                  00000500
      DO  100  I = 3, 23                                                                                 00000510
      LINK2(I) = IPACK( X(I), Y(I), 1 )                                                                  00000520
  100 CONTINUE                                                                                           00000530
      LINK2(24) = 0                                                                                      00000540
      CALL GRAPHO(IDEV, LINK2,24,5,IER)                                                                  00000550
      IF(IER.NE.0) OUTPUT(101) IER,'BAR2-1'                                                              00000560
      IF( JA .EQ. 1 )  RETURN                                                                            00000570
  200 CONTINUE                                                                                           00000580
      DO  300  I = 3, 12                                                                                 00000590
      Y(I) = CMTOGD( Y(I) )                                                                              00000600
      Y(25-I) = CMTOGD( Y(25-I) )                                                                        00000610
      W = PHI(I-2,1)*Q2(JA) + PHI(I-2,3-L)*Q3(JA) + PHI(I-2,4-L)*Q6(JA)                                  00000620
      Y(I) = W + YZERO(I)                                                                                00000630
      Y(25-I) = WTH2 + Y(I)                                                                              00000640
  300 CONTINUE                                                                                           00000650
      X(12) = CMTOGD( X(12) )                                                                            00000660
      XA = X(12)          ;   YA = Y(12)                                                                 00000670
      IF(PIN28 .EQ. NO)  GO TO 326                                                                       00000680
      IF( SENSE SWITCH 5 )  325,326                                                                      00000690
  325 CALL JOINT( 37, IRRAY9, 0.1 ,10.0, K, JA)                                                          00000700
  326 CONTINUE                                                                                           00000710
      X(12) = GDTOCM( X(12) )                                                                            00000720
      DO  350  I  = 3,12                                                                                 00000730
      Y(I) = GDTOCM( Y(I) )                                                                              00000740
      Y(25-I) = GDTOCM( Y(25-I) )                                                                        00000750
  350 CONTINUE                                                                                           00000760
      DO  400  I = 3, 23                                                                                 00000770
      LINK2(I) = IPACK( X(I), Y(I), 1 )                                                                  00000780
  400 CONTINUE                                                                                           00000790
      CALL GRAPHO(IDEV, LINK2,24,5,IER)                                                                  00000800
      IF(IER.NE.0) OUTPUT(101) IER,'BAR2-2'                                                              00000810
      RETURN                                                                                             00000820
      END                                                                                                00000830
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      SUBROUTINE BAR3(JA,LINK3,SF3,IRRAY10)                                    00000010
      DIMENSION LINK3(36), X(35), Y(35), PHI(16,3), YZERO(35)                  00000020
      COMMON AXLTH1, AXLTH2, AXLTH3, AXLTH4                                    00000030
      COMMON WTH1, WTH2, WTH3, WTH4                                            00000040
      COMMON PI, RAD, DEG, IDEV                                                00000050
      COMMON IGDIR(20), ITDIR(40)                                              00000060
      COMMON XA,YA,XB,YB,XC,YC,XD,YD,XE,YE,XF,YF,XG,YG,XH,YH,XS,YS,XP,YP00000070
      COMMON Q1(180),Q2(180),Q3(180),Q4(180),Q5(180),Q6(180),Q7(180)           00000080
      COMMON Q8(180),Q9(180),OMEGA(180)                                        00000090
      COMMON XCAM , YCAM                                                       00000100
      GDTOCM(A) = 0.2000*A - 1.0000                                            00000110
      CMTOGD(A) = A / 0.2000  +  5.000                                         00000120
      NAMELIST IER                                                             00000130
      L = 1                                                                    00000140
      K = 3                                                                    00000150
      IF( JA .NE. 1 )  GO TO 200                                               00000160
      X(1) = Y(1) = 0.0                                                        00000170
      X(2) = XG   ;    Y(2) = YG                                               00000180
      DO  10  I = 2,18                                                         00000190
      Y(I) = YZERO(I) = Y(2)                                                   00000200
      Y(I+17) = Y(2) + WTH3                                                    00000210
   10 CONTINUE                                                                 00000220
      DO  25  I = 2, 18                                                        00000230
      X(I) = X(37-I) = X(2) + FLOAT(I-2) * AXLTH3 / 16.0                       00000240
   25 CONTINUE                                                                 00000250
      XA = X(18)  ;  YA = Y(18)                                                00000260
      IF( SENSE SWITCH 5 ) 5,26                                                00000270
    5 CALL JOINT( 37, IRRAY10,0.1 ,10.0, K, JA)                                00000280
   26 CONTINUE                                                                 00000290
      AL32 = AXLTH3**2                                                         00000300
      AL33 = AXLTH3**3                                                         00000310
      DO  30  I = 3, 18                                                        00000320
      XX = X(I) - X(2)                                                         00000330
      XX2 = XX**2                                                              00000340
      XX3 = XX2 * XX                                                           00000350
      PHI(I-2,2-L) =( + 3.0*XX2*AXLTH3 - 2.0*XX3 ) * SF3/AL33                  00000360
      PHI(I-2,3-L) = ( XX*AL32 - 2.0*XX2*AXLTH3 + XX3 ) * SF3/AL32             00000370
      PHI(I-2,4-L) = -( XX2*AXLTH3 - XX3 ) * SF3/AL32                          00000380
   30 CONTINUE                                                                 00000390
      DO  50  I = 1, 35                                                        00000400
      X(I) = GDTOCM( X(I) )  ;  Y(I) = GDTOCM( Y(I) )                          00000410
   50 CONTINUE                                                                 00000420
      LINK3(1) = IHEAD(0,10)                                                   00000430
      LINK3(2) = IPACK( X(2), Y(2), 0 )                                        00000440
      DO  100  I = 3, 35                                                       00000450
      LINK3(I) = IPACK( X(I), Y(I), 1 )                                        00000460
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100 CONTINUE                                                                    00000470
    LINK3(36) = 0                                                               00000480
    CALL GRAPHO(IDEV, LINK3,36, 6, IER )                                        00000490
    IF(IER.NE.0) OUTPUT(101) IER,'BAR3-1'                                       00000500
    IF( JA .EQ. 1 )  RETURN                                                     00000510
200 CONTINUE                                                                    00000520
    DO  300  I = 3, 18                                                          00000530
    Y(I) = CMTOGD( Y(I) )                                                       00000540
    Y(37-I) = CMTOGD( Y(37-I) )                                                 00000550
    W= PHI(I-2,2-L)*Q4(JA) + PHI(I-2,3-L)*Q6(JA) + PHI(I-2,4-L)*Q5(JA)          00000560
    Y(I) = W + YZERO(I)                                                         00000570
    Y(37-I) = WTH3 + Y(I)                                                       00000580
300 CONTINUE                                                                    00000590
    X(18) = CMTOGD( X(18) )                                                     00000600
    XA = X(18)  ;  YA = Y(18)                                                   00000610
    IF( SENSE SWITCH 5 )  325,326                                               00000620
325 CALL JOINT( 37, IRRAY10,0.1 ,10.0, K, JA)                                   00000630
326 CONTINUE                                                                    00000640
    X(18) = GDTOCM( X(18) )                                                     00000650
    DO  350  I = 3, 18                                                          00000660
    Y(I) = GDTOCM( Y(I) )                                                       00000670
    Y(37-I) = GDTOCM( Y(37-I) )                                                 00000680
350 CONTINUE                                                                    00000690
    DO  400  I = 3, 35                                                          00000700
    LINK3(I) = IPACK( X(I), Y(I), 1 )                                           00000710
400 CONTINUE                                                                    00000720
    CALL GRAPHO(IDEV, LINK3,36,6,IER)                                           00000730
    IF(IER.NE.0) OUTPUT(101) IER,'BAR3-2'                                       00000740
    RETURN                                                                      00000750
    END                                                                         00000760
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```
      SUBROUTINE BAR4(JA,LINK4,SF4,SF4A)                                00000010
      DIMENSION LINK4(24), X(23), Y(23), AMP(7)                         00000020
      COMMON AXLTH1, AXLTH2, AXLTH3, AXLTH4                             00000030
      COMMON WTH1, WTH2, WTH3, WTH4                                     00000040
      COMMON PI, RAD, DEG, IDEV                                         00000050
      COMMON IGDIR(20), ITDIR(40)                                       00000060
      COMMON XA,YA,XB,YB,XC,YC,XD,YD,XE,YE,XF,YF,XG,YG,XH,YH,XS,YS,XP,YP00000070
      COMMON Q1(180),Q2(180),Q3(180),Q4(180),Q5(180),Q6(180),Q7(180)    00000080
      COMMON Q8(180),Q9(180),OMEGA(180)                                 00000090
      COMMON XCAM , YCAM                                                00000100
      GDTOCM(A) = 0.2000*A - 1.0000                                     00000110
      CMTOGD(A) = A / 0.2000  +  5.000                                  00000120
      NAMELIST IER                                                      00000130
      LINK4(1) = IHEAD(0,10)                                            00000140
      IF( JA .NE. 1 )  GO TO 500                                        00000150
      X(1) = Y(1) = 0.0                                                 00000160
      X(2) = XH    ;    Y(2) = YH                                       00000170
      X(23) = X(2)    ;   Y(23) = Y(2)                                  00000180
      X(3) = X(2) - WTH4/2.0                                            00000190
      Y(3) = Y(2) - WTH4/2.0                                            00000200
      YZERO3 = Y(3)                                                     00000210
      DO  25  I = 3, 11                                                 00000220
      X(I) = X(3)                                                       00000230
      X(25-I) = X(3) + WTH4                                             00000240
      Y(I) = Y(25-I) = Y(3) - AXLTH4 * FLOAT(I-3) / 8.0                 00000250
   25 CONTINUE                                                          00000260
      X(12) = X(11) - 1.2                                               00000270
      X(13) = X(14) + 1.2                                               00000280
      Y(12) = Y(13) = Y(11) - 0.3                                       00000290
      YZER11 = Y(11)                                                    00000300
      DO  100  I = 2, 23                                                00000310
      X(I) = GDTOCM( X(I) )  ;  Y(I) = GDTOCM( Y(I) )                   00000320
  100 CONTINUE                                                          00000330
      DO  150  I = 2, 23                                                00000340
      IF( I .EQ. 2)  LINK4(2) = IPACK( X(2), Y(2), 0 )  ;  GO TO 150    00000350
      LINK4(I) = IPACK( X(I), Y(I), 1 )                                 00000360
  150 CONTINUE                                                          00000370
      LINK4(24) = 0                                                     00000380
      CALL GRAPHO(IDEV,LINK4,24,7,IER)                                  00000390
      IF(IER.NE.0) OUTPUT(101) IER,'BAR4-1'                             00000400
      DO  275  I = 1,22                                                 00000410
  275 CONTINUE                                                          00000420
      IF( JA .EQ. 1 )  RETURN                                           00000430
  500 DO  550  I = 2,23                                                 00000440
      X(I) = CMTOGD( X(I) )    ;  Y(I) = CMTOGD( Y(I) )                 00000450
  550 CONTINUE                                                          00000460
```

```
      Y(3) = Y(22) =  YZERO3 + Q4(JA)*SF4                                    00000470
      Y(2) = Y(3) + 0.2                                                      00000480
      Y(23) = Y(2)                                                           00000490
      Y(11) = Y(14) = YZER11 -  Q7(JA)*SF4                                   00000500
      Y(12) = Y(13) = Y(11) - 0.3                                            00000510
      DIFF = ABS( Y(3) - Y(11) ) - AXLTH4                                    00000520
      DO  560  I = 4, 10                                                     00000530
      Y(I)  = Y(25-I) = Y(3) - ( FLOAT(I-3) * (Y(3)-Y(11)) / 8.0)            00000540
560   CONTINUE                                                               00000550
      DO  575  I = 4, 7                                                      00000560
      AMP(I) = DIFF*SIN( FLOAT(I-3) * PI/8.0 ) * SF4A                        00000570
      IF( AMP(I)  .GT. WTH4/2.0 )    AMP(I) = WTH4/2.0                       00000580
      X(I) = X(14-I) =  X(3) + AMP(I)                                        00000590
      X(25-I) = X(I+11) = X(I) + WTH4 - 2.0 * AMP(I)                         00000600
575   CONTINUE                                                               00000610
      DO  600  I = 2,23                                                      00000620
      X(I) = GDTOCM( X(I) )  ;  Y(I) = GDTOCM( Y(I) )                        00000630
      LINK4(I) = IPACK( X(I), Y(I), 1 )                                      00000640
600   CONTINUE                                                               00000650
      LINK4(2) = IPACK( X(2), Y(2), 0 )                                      00000660
      LINK4(24) = 0                                                          00000670
      CALL GRAPHO(IDEV,LINK4,24,7,IER)                                       00000680
      IF(IER.NE.0) OUTPUT(101) IER,'BAR4-2'                                  00000690
      RETURN                                                                 00000700
      END                                                                    00000710
```

```
      SUBROUTINE CAM(NCAM,ICAM,RADIUS,AMP,JA,RADCOS,RADSIN)                  00000010
      DIMENSION ICAM(NCAM), X(97), Y(97), RADCOS(97), RADSIN(97)             00000020
      COMMON AXLTH1, AXLTH2, AXLTH3, AXLTH4                                  00000030
      COMMON WTH1, WTH2, WTH3, WTH4                                          00000040
      COMMON PI, RAD, DEG, IDEV                                              00000050
      COMMON IGDIR(20), ITDIR(40)                                            00000060
      COMMON XA,YA,XB,YB,XC,YC,XD,YD,XE,YE,XF,YF,XG,YG,XH,YH,XS,YS,XP,YP00000070
      COMMON Q1(180),Q2(180),Q3(180),Q4(180),Q5(180),Q6(180),Q7(180)         00000080
      COMMON Q8(180),Q9(180),OMEGA(180)                                      00000090
      COMMON XCAM , YCAM                                                     00000100
      CMTOGD(A) = A / 0.2000  +  5.000                                       00000110
      GDTOCM(A) = 0.2000*A - 1.0000                                          00000120
      X(1) = 0.0          ;   Y(1) = 0.0                                     00000130
      IF( JA .NE. 1 )  GO TO 55                                              00000140
      ICAM(1) = IHEAD(0,10)                                                  00000150
      CROSS = 0.3                                                            00000160
      XCAM = XE - AMP                                                        00000170
      X(2) = XCAM + CROSS                                                    00000180
      X(3) = XCAM - CROSS                                                    00000190
      YCAM = YD - 0.6 - AXLTH1 - RADIUS + YS                                 00000200
      Y(2) = YCAM + CROSS ;  Y(3) = YCAM - CROSS                             00000210
      X(4) = X(5) = Y(4) = Y(5) = 0.0                                        00000220
      DO  30  I = 1,3                                                        00000230
      X(I) = GDTOCM( X(I) )  ;  Y(I) = GDTOCM( Y(I) )                        00000240
   30 CONTINUE                                                               00000250
      XCAM = GDTOCM( XCAM )  ;  YCAM = GDTOCM( YCAM )                        00000260
      ICAM(2) = IPACK( X(2), YCAM, 0 )                                       00000270
      ICAM(3) = IPACK( X(3), YCAM, 1 )                                       00000280
      ICAM(4) = IPACK( XCAM, Y(2), 0 )                                       00000290
      ICAM(5) = IPACK( XCAM, Y(3), 1 )                                       00000300
   55 CONTINUE                                                               00000310
      IF( JA .EQ. 1 )  XCAM = CMTOGD( XCAM )    ;  YCAM = CMTOGD( YCAM )00000320
      XE = XCAM + COS(OMEGA(JA))                                             00000330
      YE = Q9(JA) + YCAM                                                     00000340
      X(6) = RADIUS + XE  ;  Y(6) = YE                                       00000350
      DO 200 I = 6, NCAM-1                                                   00000360
      X(I+1) = RADCOS(I+1) + XE                                              00000370
      Y(I+1) = RADSIN(I+1) + YE                                              00000380
      X(I) = GDTOCM( X(I) )  ;  Y(I) = GDTOCM( Y(I) )                        00000390
      IF(I.EQ.6) ICAM(6)= IPACK(X(6),Y(6),0); GO TO 200                      00000400
      ICAM(I)= IPACK(X(I),Y(I),1)                                            00000410
  200 CONTINUE                                                               00000420
      ICAM(NCAM) = 0                                                         00000430
      CALL GRAPHO(IDEV,ICAM,NCAM,1,IER)                                      00000440
      RETURN                                                                 00000450
      END                                                                    00000460
```

```
      SUBROUTINE  DISPLY(CONFIG, K, I105, I109, I117, I101,I104)          00000010
      DIMENSION I101(7), I104(8), I105(3), I109(7), I117(5), CONFIG(180)00000020
      INTEGER ROTATE, CONFIG, YES, BLNK                                   00000030
      COMMON AXLTH1, AXLTH2, AXLTH3, AXLTH4                               00000040
      COMMON WTH1, WTH2, WTH3, WTH4                                       00000050
      COMMON PI, RAD, DEG, IDEV                                           00000060
      COMMON IGDIR(20), ITDIR(40)                                         00000070
      COMMON XA,YA,XB,YB,XC,YC,XD,YD,XE,YE,XF,YF,XG,YG,XH,YH,XS,YS,XP,YP00000080
      COMMON Q1(180),Q2(180),Q3(180),Q4(180),Q5(180),Q6(180),Q7(180)      00000090
      COMMON Q8(180),Q9(180),OMEGA(180)                                   00000100
      COMMON XCAM , YCAM                                                  00000110
      DATA NULL/77777777B/, BLNK/4H    /, YES/4HYES /, NO/4HNO  /         00000120
      NAMELIST IER                                                        00000130
      GO TO(1501,1502,1503,1504,1505,1506,1507,1508) CONFIG(K)            00000140
 1501 CONTINUE                                                            00000150
      CALL TEXTO(IDEV,NULL, 1,26,30,2,3,IER)                              00000160
      IF(IER.NE.0) OUTPUT(101) IER                                        00000170
      CALL TEXTO(IDEV,I105, 3,26,30,2,3,IER)                              00000180
      IF(IER.NE.0) OUTPUT(101) IER                                        00000190
      CALL TEXTO(IDEV,NULL, 1,28,30,2,3,IER)                              00000200
      IF(IER.NE.0) OUTPUT(101) IER                                        00000210
      CALL TEXTO(IDEV,NULL, 1,30,30,2,3,IER)                              00000220
      IF(IER.NE.0) OUTPUT(101) IER                                        00000230
      CALL TEXTO(IDEV,NULL, 1,32,30,2,3,IER)                              00000240
      IF(IER.NE.0) OUTPUT(101) IER                                        00000250
      GO TO 1509                                                          00000260
 1502 CONTINUE                                                            00000270
      CALL TEXTO(IDEV,NULL, 1,26,30,2,3,IER)                              00000280
      IF(IER.NE.0) OUTPUT(101) IER                                        00000290
      CALL TEXTO(IDEV,I109, 3,26,30,2,3,IER)                              00000300
      IF(IER.NE.0) OUTPUT(101) IER                                        00000310
      CALL TEXTO(IDEV,NULL, 1,28,30,2,3,IER)                              00000320
      IF(IER.NE.0) OUTPUT(101) IER                                        00000330
      CALL TEXTO(IDEV,NULL, 1,30,30,2,3,IER)                              00000340
      IF(IER.NE.0) OUTPUT(101) IER                                        00000350
      CALL TEXTO(IDEV,I117, 5,32,30,2,3,IER)                              00000360
      IF(IER.NE.0) OUTPUT(101) IER                                        00000370
      GO TO 1509                                                          00000380
 1503 CONTINUE                                                            00000390
      CALL TEXTO(IDEV,NULL, 1,26,30,2,3,IER)                              00000400
      IF(IER.NE.0) OUTPUT(101) IER                                        00000410
      CALL TEXTO(IDEV,I109, 3,26,30,2,3,IER)                              00000420
      IF(IER.NE.0) OUTPUT(101) IER                                        00000430
      CALL TEXTO(IDEV,I101, 7,28,30,2,3,IER)                              00000440
      IF(IER.NE.0) OUTPUT(101) IER                                        00000450
      CALL TEXTO(IDEV,NULL, 1,30,30,2,3,IER)                              00000460
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      IF(IER.NE.0) OUTPUT(101) IER                                    00000470
      CALL TEXTO(IDEV,NULL, 1,32,30,2,3,IER)                          00000480
      GO TO 1509                                                      00000490
 1504 CONTINUE                                                        00000500
      CALL TEXTO(IDEV,NULL, 1,26,30,2,3,IER)                          00000510
      IF(IER.NE.0) OUTPUT(101) IER                                    00000520
      CALL TEXTO(IDEV,I109, 3,26,30,2,3,IER)                          00000530
      IF(IER.NE.0) OUTPUT(101) IER                                    00000540
      CALL TEXTO(IDEV,I101, 7,28,30,2,3,IER)                          00000550
      IF(IER.NE.0) OUTPUT(101) IER                                    00000560
      CALL TEXTO(IDEV,NULL, 1,30,30,2,3,IER)                          00000570
      IF(IER.NE.0) OUTPUT(101) IER                                    00000580
      CALL TEXTO(IDEV,I117, 5,32,30,2,3,IER)                          00000590
      IF(IER.NE.0) OUTPUT(101) IER                                    00000600
      GO TO 1509                                                      00000610
 1505 CONTINUE                                                        00000620
      CALL TEXTO(IDEV,NULL, 1,26,30,2,3,IER)                          00000630
      IF(IER.NE.0) OUTPUT(101) IER                                    00000640
      CALL TEXTO(IDEV,I109, 3,26,30,2,3,IER)                          00000650
      IF(IER.NE.0) OUTPUT(101) IER                                    00000660
      CALL TEXTO(IDEV,NULL, 1,28,30,2,3,IER)                          00000670
      IF(IER.NE.0) OUTPUT(101) IER                                    00000680
      CALL TEXTO(IDEV,I104, 8,30,30,2,3,IER)                          00000690
      IF(IER.NE.0) OUTPUT(101) IER                                    00000700
      CALL TEXTO(IDEV,NULL, 1,32,30,2,3,IER)                          00000710
      IF(IER.NE.0) OUTPUT(101) IER                                    00000720
      GO TO 1509                                                      00000730
 1506 CONTINUE                                                        00000740
      CALL TEXTO(IDEV,NULL, 1,26,30,2,3,IER)                          00000750
      IF(IER.NE.0) OUTPUT(101) IER                                    00000760
      CALL TEXTO(IDEV,I109, 3,26,30,2,3,IER)                          00000770
      IF(IER.NE.0) OUTPUT(101) IER                                    00000780
      CALL TEXTO(IDEV,NULL, 1,28,30,2,3,IER)                          00000790
      IF(IER.NE.0) OUTPUT(101) IER                                    00000800
      CALL TEXTO(IDEV,I104, 8,30,30,2,3,IER)                          00000810
      IF(IER.NE.0) OUTPUT(101) IER                                    00000820
      CALL TEXTO(IDEV,I117, 5,32,30,2,3,IER)                          00000830
      IF(IER.NE.0) OUTPUT(101) IER                                    00000840
      GO TO 1509                                                      00000850
 1507 CONTINUE                                                        00000860
      CALL TEXTO(IDEV,NULL, 1,26,30,2,3,IER)                          00000870
      IF(IER.NE.0) OUTPUT(101) IER                                    00000880
      CALL TEXTO(IDEV,I109, 3,26,30,2,3,IER)                          00000890
      IF(IER.NE.0) OUTPUT(101) IER                                    00000900
      CALL TEXTO(IDEV,I101, 7,28,30,2,3,IER)                          00000910
      IF(IER.NE.0) OUTPUT(101) IER                                    00000920
      CALL TEXTO(IDEV,I104, 8,30,30,2,3,IER)                          00000930
      IF(IER.NE.0) OUTPUT(101) IER                                    00000940
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      CALL TEXTO(IDEV,NULL, 1,32,30,2,3,IER)                    00000950
      IF(IER.NE.0) OUTPUT(101) IER                              00000960
      GO TO 1509                                                00000970
 1508 CONTINUE                                                  00000980
      CALL TEXTO(IDEV,NULL, 1,26,30,2,3,IER)                    00000990
      IF(IER.NE.0) OUTPUT(101) IER                              00001000
      CALL TEXTO(IDEV,I109, 3,26,30,2,3,IER)                    00001010
      IF(IER.NE.0) OUTPUT(101) IER                              00001020
      CALL TEXTO(IDEV,I101, 7,28,30,2,3,IER)                    00001030
      IF(IER.NE.0) OUTPUT(101) IER                              00001040
      CALL TEXTO(IDEV,I104, 8,30,30,2,3,IER)                    00001050
      IF(IER.NE.0) OUTPUT(101) IER                              00001060
      CALL TEXTO(IDEV,I117, 5,32,30,2,3,IER)                    00001070
      IF(IER.NE.0) OUTPUT(101) IER                              00001080
 1509 CONTINUE                                                  00001090
      RETURN                                                    00001100
      END                                                       00001110
```

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      SUBROUTINE INITAL(CONFIG, IRRAY1,                                 00000010
     1            IRRAY2,IRRAY3,IRRAY4,IRRAY5,IRRAY6,IRRAY7,IRRAY9,     00000020
     2            IRRAY10,ISPRING)                                      00000030
      INTEGER CONFIG, YES, BLNK                                         00000040
      DIMENSION IRRAY1( 97),IRRAY2( 18),IRRAY3(13),IRRAY4(32)           00000050
      DIMENSION IRRAY5(24), IRRAY6(36),IRRAY7(24),ISPRNG(9),IRRAY9( 49) 00000060
      DIMENSION IRRAY10( 49), I101(7)                                   00000070
      DIMENSION I106(12), I107(11), I108( 7), I109( 7), I110(2)         00000080
      DIMENSION I111( 5), I112( 9), I113( 8), I114(18), I115(1),I116(10)00000090
      DIMENSION CONFIG(180), I117(5)                                    00000100
      COMMON AXLTH1, AXLTH2, AXLTH3, AXLTH4                             00000110
      COMMON WTH1, WTH2, WTH3, WTH4                                     00000120
      COMMON PI, RAD, DEG, IDEV                                         00000130
      COMMON IGDIR(20), ITDIR(40)                                       00000140
      COMMON XA,YA,XB,YB,XC,YC,XD,YD,XE,YE,XF,YF,XG,YG,XH,YH,XS,YS,XP,YP00000150
      COMMON Q1(180),Q2(180),Q3(180),Q4(180),Q5(180),Q6(180),Q7(180)    00000160
      COMMON Q8(180),Q9(180),OMEGA(180)                                 00000170
      COMMON XCAM , YCAM                                                00000180
      DATA NULL/77777777B/, BLNK/4H    /, YES/4HYES /, NO/4HNO  /       00000190
      NAMELIST IER                                                      00000200
  101 FORMAT('  CAM ACTUATED VALVE TRAIN  ')                           00000210
  106 FORMAT('  THIS PROGRAM SIMULATES AN ELASTIC LINK MODEL  ')         00000220
  107 FORMAT(' OF AN AUTOMOBILE CAM ACTUATED VALVE TRAIN ')             00000230
  108 FORMAT(' LT. CHARLES W. GNILKA USN  ')                            00000240
  109 FORMAT(' VILLANOVA UNIVERSITY 1964  ')                            00000250
  110 FORMAT('ADVISOR ')                                                00000260
  111 FORMAT('DAVID  SALINAS, PHD ')                                    00000270
  112 FORMAT('PROFESSOR OF MECHANICAL ENGINEERING ')                    00000280
  113 FORMAT('U. S. NAVAL POSTGRADUATE SCHOOL ')                        00000290
  114 FORMAT('FORMER  ADVISOR:  RICHARD  C.  WINFREY, PHD ')            00000300
  115 FORMAT(' BY ')                                                    00000310
  116 FORMAT('NAVAL CIVIL ENG. LAB, PORT HUENEME, CAL.')                00000320
  117 FORMAT(' WITH  CLEARANCES   ')                                    00000330
      IF(IDEV.EQ.1) OUTPUT(6) '   AGT-1'                              00000340
      IF(IDEV.EQ.2) OUTPUT(6) '   AGT-2'                              00000350
      OUTPUT(101) IDEV,'INPUT CHANGES' ;   INPUT(101)                   00000360
      DO 10 JA =1,20                                                    00000370
   10 IGDIR(JA) = 0                                                     00000380
      CALL DGINIT(IDEV,IGDIR,20,IER)                                    00000390
      IF(IER.NE.0) OUTPUT(101) IER                                      00000400
      CALL DTINIT(IDEV,ITDIR,40,IER)                                    00000410
      IF(IER.NE.0) OUTPUT(101) IER                                      00000420
C     INITIALIZE TEXTI BLOCK                                            00000430
      CALL TEXTO(IDEV,NULL,1,39,46,2,3,IER)                             00000440
      IF(IER.NE.0) OUTPUT(101) IER                                      00000450
      ENCODE(28,101,I101)                                               00000460
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      ENCODE(48,106,I106)                                                00000470
      ENCODE(44,107,I107)                                                00000480
      ENCODE(28,108,I108)                                                00000490
      ENCODE(28,109,I109)                                                00000500
      ENCODE( 8,110,I110)                                                00000510
      ENCODE(20,111,I111)                                                00000520
      ENCODE(36,112,I112)                                                00000530
      ENCODE(32,113,I113)                                                00000540
      ENCODE(44,114,I114)                                                00000550
      ENCODE( 4,115,I115)                                                00000560
      ENCODE(40,116,I116)                                                00000570
      ENCODE(20, 117,I117)                                               00000580
      CALL TEXTO(IDEV,I101,7,1,13,3,3,IER)                               00000590
      IF(IER.NE.0) OUTPUT(101) IER                                       00000600
      CALL TEXTO(IDEV, I106,12, 5, 1,2,3,IER)                            00000610
      IF(IER.NE.0) OUTPUT(101) IER                                       00000620
      CALL TEXTO(IDEV, I107,11, 8, 6,2,3,IER)                            00000630
      IF(IER.NE.0) OUTPUT(101) IER                                       00000640
      CALL TEXTO(IDEV,I115,1,14,45,2,3,IER)                              00000650
      IF(IER.NE.0) OUTPUT(101) IER                                       00000660
      CALL TEXTO(IDEV, I108, 7,17,25,2,3,IER)                            00000670
      IF(IER.NE.0) OUTPUT(101) IER                                       00000680
      CALL TEXTO(IDEV, I109, 7,19,37,1,3,IER)                            00000690
      IF(IER.NE.0) OUTPUT(101) IER                                       00000700
      CALL TEXTO(IDEV, I110, 2,24,43,2,3,IER)                            00000710
      IF(IER.NE.0) OUTPUT(101) IER                                       00000720
      CALL TEXTO(IDEV, I111, 5,27,29,2,3,IER)                            00000730
      IF(IER.NE.0) OUTPUT(101) IER                                       00000740
      CALL TEXTO(IDEV, I112, 9,29,31,1,3,IER)                            00000750
      IF(IER.NE.0) OUTPUT(101) IER                                       00000760
      CALL TEXTO(IDEV, I113, 8,30,33,1,3,IER)                            00000770
      IF(IER.NE.0) OUTPUT(101) IER                                       00000780
      CALL TEXTO(IDEV, I114,11,33,30,1,3,IER)                            00000790
      IF(IER.NE.0) OUTPUT(101) IER                                       00000800
      CALL TEXTO(IDEV, I116,10,34,33,1,3,IER)                            00000810
      IF(IER.NE.0) OUTPUT(101) IER                                       00000820
      CALL TEXTO(IDEV, I117, 5,11,27,2,3,IER)                            00000830
      IF(IER.NE.0) OUTPUT(101) IER                                       00000840
C     PAUSE TO READ TITLE PAGE                                           00000850
      CALL TEXTR(IDEV,NULL,1,39,46,2,3,IER)                              00000860
      IF(IER.NE.0) OUTPUT(101) IER                                       00000870
   12 IF(MOD(ITDIR(1),8).EQ.0)  GO TO 12                                 00000880
      CALL TEXTO(IDEV,NULL,1,39,46,2,3,IER)                              00000890
      IF(IER.NE.0) OUTPUT(101) IER                                       00000900
      DO 20 JA = 1,97                                                    00000910
   20 IRRAY1(JA) = 0.0                                                   00000920
      DO 21 JA = 1,18                                                    00000930
   21 IRRAY2(JA) = 0.0                                                   00000940
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      DO 22 JA = 1,11                                                    00000950
   22 IRRAY3(JA) = 0.0                                                   00000960
      DO 23 JA = 1,32                                                    00000970
   23 IRRAY4(JA) = 0.0                                                   00000980
      DO  24  JA = 1,24                                                  00000990
   24 IRRAY5(JA) = 0.0                                                   00001000
      DO  25  JA = 1,36                                                  00001010
   25 IRRAY6(JA) = 0.0                                                   00001020
      DO  26  JA = 1,24                                                  00001030
   26 IRRAY7(JA) = 0.0                                                   00001040
      DO  27  JA = 1,9                                                   00001050
   27 ISPRNG(JA) = 0.0                                                   00001060
      DO  28  JA = 1,49                                                  00001070
   28 IRRAY9(JA) = 0.0                                                   00001080
      DO  29  JA = 1,49                                                  00001090
   29 IRRAY10(JA) = 0.0                                                  00001100
      IRRAY1(1) = IHEAD(0,10)                                            00001110
      IRRAY2(1) = IHEAD(0,10)                                            00001120
      IRRAY3(1) = IHEAD(0,10)                                            00001130
      IRRAY4(1) = IHEAD(0,10)                                            00001140
      IRRAY5(1) = IHEAD(0,10)                                            00001150
      IRRAY6(1) = IHEAD(0,10)                                            00001160
      IRRAY7(1) = IHEAD(0,10)                                            00001170
      ISPRNG(1) = IHEAD(0,10)                                            00001180
      IRRAY9(1) = IHEAD(0,10)                                            00001190
      IRRAY10(1) = IHEAD(0,10)                                           00001200
      CALL GRAPHO (IDEV,IRRAY1, 97,1,IER)                                00001210
      IF(IER.NE.0) OUTPUT(101) IER,'IRRAY1'                              00001220
      CALL GRAPHO (IDEV,IRRAY2, 18,2,IER)                                00001230
      IF(IER.NE.0) OUTPUT(101) IER,'IRRAY2'                              00001240
      CALL GRAPHO (IDEV,IRRAY3, 13,3,IER)                                00001250
      IF(IER.NE.0) OUTPUT(101) IER,'IRRAY3'                              00001260
      CALL GRAPHO (IDEV,IRRAY4, 32,4,IER)                                00001270
      IF(IER.NE.0) OUTPUT(101) IER,'IRRAY4'                              00001280
      CALL GRAPHO (IDEV,IRRAY5, 24,5,IER)                                00001290
      IF(IER.NE.0) OUTPUT(101) IER,'IRRAY5'                              00001300
      CALL GRAPHO (IDEV,IRRAY6, 36,6,IER)                                00001310
      IF(IER.NE.0) OUTPUT(101) IER,'IRRAY6'                              00001320
      CALL GRAPHO(IDEV,IRRAY7,24,7,IER)                                  00001330
      IF(IER.NE.0) OUTPUT(101) IER,'IRRAY7'                              00001340
      CALL GRAPHO(IDEV,ISPRNG,9,8,IER)                                   00001350
      IF(IER.NE.0) OUTPUT(101) IER,'IRRAY8'                              00001360
      CALL GRAPHO (IDEV,IRRAY9, 49,9,IER)                                00001370
      IF(IER.NE.0) OUTPUT(101) IER,'IRRAY9'                              00001380
      CALL GRAPHO (IDEV,IRRAY10, 49,10,IER)                              00001390
      IF(IER.NE.0) OUTPUT(101) IER,'IRRAY10'                             00001400
      RETURN                                                             00001410
      END                                                                00001420
```

```
      SUBROUTINE JOINT(NCIR,ICIR, RADIUS, ANGLE, K, JA)                          00000010
      DIMENSION ICIR(NCIR), X( 75), Y( 75), RADCOS( 75), RADSIN( 75)             00000020
      COMMON AXLTH1, AXLTH2, AXLTH3, AXLTH4                                      00000030
      COMMON WTH1, WTH2, WTH3, WTH4                                              00000040
      COMMON PI, RAD, DEG, IDEV                                                  00000050
      COMMON IGDIR(20), ITDIR(40)                                                00000060
      COMMON XA,YA,XB,YB,XC,YC,XD,YD,XE,YE,XF,YF,XG,YG,XH,YH,XS,YS,XP,YP00000070
      COMMON Q1(180),Q2(180),Q3(180),Q4(180),Q5(180),Q6(180),Q7(180)             00000080
      COMMON Q8(180),Q9(180),OMEGA(180)                                          00000090
      COMMON XCAM , YCAM                                                         00000100
      GDTOCM(A) = 0.2000*A - 1.0000                                              00000110
      NAMELIST IER                                                               00000120
      IF( JA .NE. 1 )  GO TO 35                                                  00000130
      ICIR(1) = IHEAD(1,10)                                                      00000140
      X(1)=Y(1)=0.0                                                              00000150
      THETA = 0.0                                                                00000160
      DTHETA= ANGLE * RAD                                                        00000170
      DO  25  I = 3, NCIR                                                        00000180
      THETA = THETA + DTHETA                                                     00000190
      RADCOS(I) = RADIUS*COS(THETA)                                              00000200
      RADSIN(I) = RADIUS*SIN(THETA)                                              00000210
   25 CONTINUE                                                                   00000220
   35 CONTINUE                                                                   00000230
      X(2) = RADIUS + XA  ;  Y(2) = YA                                           00000240
      DO 100 I = 3,NCIR                                                          00000250
      X(I) = RADCOS(I) + XA                                                      00000260
      Y(I) = RADSIN(I) + YA                                                      00000270
  100 CONTINUE                                                                   00000280
X     OUTPUT(6) '    JOINT CALLED'                                             00000290
      DO 200 I = 2, NCIR                                                         00000300
X     WRITE(6,99) I, X(I), Y(I)                                                  00000310
X  99 FORMAT(' ',3X,'I=',I3,2E15.4)                                             00000320
      X(I) = GDTOCM( X(I) )  ;  Y(I) = GDTOCM( Y(I) )                            00000330
      IF(I.EQ.2) ICIR(2)= IPACK(X(2),Y(2),0); GO TO 200                          00000340
      ICIR(I)= IPACK(X(I),Y(I),1)                                                00000350
  200 CONTINUE                                                                   00000360
      CALL GRAPHO(IDEV,ICIR,NCIR,7+K,IER)                                        00000370
      IF(IER.NE.0) OUTPUT(101) IER                                               00000380
      RETURN                                                                     00000390
      END                                                                        00000400
```

```
      SUBROUTINE MIDBAR(MIDCIR,IRRAY9)                                  00000010
      DIMENSION MIDCIR(18), X(18), Y(18), IRRAY9(49)                    00000020
      COMMON AXLTH1, AXLTH2, AXLTH3, AXLTH4                             00000030
      COMMON WTH1, WTH2, WTH3, WTH4                                     00000040
      COMMON PI, RAD, DEG, IDEV                                         00000050
      COMMON IGDIR(20), ITDIR(40)                                       00000060
      COMMON XA,YA,XB,YB,XC,YC,XD,YD,XE,YE,XF,YF,XG,YG,XH,YH,XS,YS,XP,YP00000070
      COMMON Q1(180),Q2(180),Q3(180),Q4(180),Q5(180),Q6(180),Q7(180)    00000080
      COMMON Q8(180),Q9(180),OMEGA(180)                                 00000090
      COMMON XCAM , YCAM                                                00000100
      NAMELIST IER                                                      00000110
      GDTOCM(A) = 0.2000*A - 1.0000                                     00000120
      MIDCIR(1) = IHEAD(0,10)                                           00000130
      X(1)=Y(1)=0.0                                                     00000140
      ANGLE = 9.0  ;  K = 6   ;  JA = 1                                 00000150
      RADIUS= 0.25                                                      00000160
      XA = XB   ;  YA = YB                                              00000170
      CALL JOINT(49, IRRAY9, RADIUS, ANGLE,K, JA)                       00000180
      DO  100  I = 1, 49                                                00000190
      IRRAY9(I) = 0                                                     00000200
  100 CONTINUE                                                          00000210
      X(  2) = XB ; Y(  2) = YB                                         00000220
      X(  3) = XB + .5  ;  Y(  3) = YB - .5                             00000230
      X(  4) = X(  3) - 1.0  ;  Y(  4) = Y(  3)                         00000240
      X(  5) = X(  2)  ;  Y(  5) = Y(  2)                               00000250
      X(  6) = X(  3)  ;  Y(  6) = Y(  3)                               00000260
      DO 150 I = 1,11                                                   00000270
      X(  6 + I) = X(  5+I) - .1                                        00000280
  150 CONTINUE                                                          00000290
      DO  160  I = 7,17,2                                               00000300
      Y(I) = Y(  6) - .1                                                00000310
      Y(I+1) = Y(  6)                                                   00000320
  160 CONTINUE                                                          00000330
      DO 200 I = 2, 17                                                  00000340
      X(I) = GDTOCM( X(I) )  ;  Y(I) = GDTOCM( Y(I) )                   00000350
      IF(I.EQ.2 )   MIDCIR(I)=IPACK(X(I),Y(I),0); GO TO 200             00000360
      MIDCIR(I) = IPACK(X(I),Y(I),1)                                    00000370
  200 CONTINUE                                                          00000380
      DO 250 I = 8, 18, 2                                               00000390
      MIDCIR(I) = IPACK(X(I),Y(I),0)                                    00000400
  250 CONTINUE                                                          00000410
      MIDCIR( 18) = 0                                                   00000420
      CALL GRAPHO(IDEV,MIDCIR, 18,2,IER)                                00000430
X     IF(IER.NE.0) OUTPUT(101) IER                                      00000440
      RETURN                                                            00000450
      END                                                               00000460
```

```
      SUBROUTINE READ(NTIME, I104, I105, XZERO, AMP, RPM, WN, ISEAT,     00000010
     1                PIN28, CONFIG, DIFF)                               00000020
      INTEGER CONFIG, YES, BLNK                                         00000030
      DIMENSION I104(8), I105(3), CONFIG(180)                           00000040
      COMMON AXLTH1, AXLTH2, AXLTH3, AXLTH4                             00000050
      COMMON WTH1, WTH2, WTH3, WTH4                                     00000060
      COMMON PI, RAD, DEG, IDEV                                         00000070
      COMMON IGDIR(20), ITDIR(40)                                       00000080
      COMMON XA,YA,XB,YB,XC,YC,XD,YD,XE,YE,XF,YF,XG,YG,XH,YH,XS,YS,XP,YP00000090
      COMMON Q1(180),Q2(180),Q3(180),Q4(180),Q5(180),Q6(180),Q7(180)    00000100
      COMMON Q8(180),Q9(180),OMEGA(180)                                 00000110
      COMMON XCAM , YCAM                                                00000120
      DATA NULL/77777777B/, BLNK/4H    /, YES/4HYES /, NO/4HNO  /       00000130
      NAMELIST IER                                                      00000140
   30 FORMAT(5E15.7)                                                    00000150
   31 FORMAT(5E15.7, I3)                                                00000160
   40 FORMAT(' ', 4X, I3, 2X, 9(2X,1PE10.3), 6X, I2)                    00000170
   45 FORMAT('0', 2X, 'DEGREES', 6X, 'Q1', 10X, 'Q2', 10X, 'Q3', 10X,   00000180
     1        'Q4', 10X, 'Q5', 10X, 'Q6', 10X, 'Q7', 10X, 'Q8', 8X,     00000190
     2        'OMEGA', 7X, 'CONFIG', //)                                00000200
  104 FORMAT(' LISTING OF COORDINATES DESIRED ')                        00000210
  105 FORMAT('  COMMAND:  ')                                           00000220
 5012 FORMAT('1', 20X, 20A4)                                            00000230
 5013 FORMAT('0', 20X, 20A4)                                            00000240
 5014 FORMAT(18A4)                                                      00000250
 5015 FORMAT(5E10.4, 2A4)                                               00000260
 5016 FORMAT('0',   ' XZERO =',E10.4,'     AMP =',E10.4,'    RPM=',E10.4,00000270
     1   '    NAT. FREQ =',3PE10.1,6X,1A4,' VALVE SEAT ', 1A4,          00000280
     2    ' COORD. 2 AND 8 PINNED')                                     00000290
 5017 FORMAT('0', 10X, 'AT ZERO DEGREES - - CLEARANCE BETWEEN VALVE'    00000300
     1        ' AND VALVE SEAT IS ', F7.3)                              00000310
    4 REWIND 4                                                          00000320
      READ(4,5014) (Q1(JA),JA=1,18)                                     00000330
      READ(4,5014) (Q2(JA),JA=1,18)                                     00000340
      READ(4,5015) XZERO,AMP,RPM,WN,CLEAR, ISEAT, PIN28                 00000350
      WRITE(6,5012) (Q1(JA),JA=1,18)                                    00000360
      WRITE(6,5013) (Q2(JA),JA=1,18)                                    00000370
      WRITE(6,5016) XZERO,AMP,RPM,WN,ISEAT,PIN28                        00000380
C     DESIRE COORDINATES PRINTED                                        00000390
      ENCODE(32,104,I104)                                               00000400
      ENCODE(12,105,I105)                                               00000410
      CALL TEXTO(IDEV,I104,8,37,17,2,3,IER)                             00000420
      IF(IER.NE.0) OUTPUT(101) IER                                      00000430
      CALL TEXTO(IDEV,I105,3,39,23,2,3,IER)                             00000440
      IF(IER.NE.0) OUTPUT(101) IER                                      00000450
      CALL TEXTR(IDEV,NULL,1,39,46,2,3,IER)                             00000460
```

```
      IF(IER.NE.0) OUTPUT(101) IER                                      00000470
   15 IF(MOD(ITDIR(1),8).EQ.0)  GO TO 15                                00000480
      CALL TEXTI(IDEV,IMODA,1,39,46,IER)                                00000490
      IF(IER.NE.0) OUTPUT(101) IER                                      00000500
      IPRINT = NO                                                       00000510
      IF( IMODA .EQ. YES )  IPRINT = YES                                00000520
C     ERASE QUESTION                                                    00000530
      CALL TEXTO(IDEV,NULL,1,39,46,2,3,IER)                             00000540
      IF(IER.NE.0) OUTPUT(101) IER                                      00000550
      CALL TEXTO(IDEV,NULL,1,39,23,2,3,IER)                             00000560
      IF(IER.NE.0) OUTPUT(101) IER                                      00000570
      CALL TEXTO(IDEV,NULL,1,37,17,2,3,IER)                             00000580
      IF(IER.NE.0) OUTPUT(101) IER                                      00000590
      READ(4,30) DIFF                                                   00000600
      WRITE(6,5017) DIFF                                                00000610
      DO  1000  I = 1,NTIME                                             00000620
      READ(4,30) Q1(I),Q2(I),Q3(I),Q4(I),Q5(I)                          00000630
      READ(4,31) Q6(I),Q7(I),Q8(I),Q9(I),OMEGA(I),CONFIG(I)             00000640
 1000 CONTINUE                                                          00000650
      IF( IPRINT .EQ. NO )   GO TO 1250                                 00000660
 1100 WRITE(6,45)                                                       00000670
      DO  1200  I = 1, NTIME                                            00000680
      NDEG = IFIX( OMEGA(I)*DEG )                                       00000690
      WRITE(6,40) NDEG,Q1(I),Q2(I),Q3(I),Q4(I),Q5(I),Q6(I),Q7(I),       00000700
     1            Q8(I),OMEGA(I), CONFIG(I)                             00000710
 1200 CONTINUE                                                          00000720
 1250 CONTINUE                                                          00000730
C     NULL TITLE PAGE                                                   00000740
      CALL TEXTO(IDEV, NULL, 1, 5, 1,2,3,IER)                           00000750
      IF(IER.NE.0) OUTPUT(101) IER                                      00000760
      CALL TEXTO(IDEV, NULL, 1, 8, 6,2,3,IER)                           00000770
      IF(IER.NE.0) OUTPUT(101) IER                                      00000780
      CALL TEXTO(IDEV,NULL,1,14,45,2,3,IER)                             00000790
      IF(IER.NE.0) OUTPUT(101) IER                                      00000800
      CALL TEXTO(IDEV, NULL, 1,17,25,2,3,IER)                           00000810
      IF(IER.NE.0) OUTPUT(101) IER                                      00000820
      CALL TEXTO(IDEV, NULL, 1,19,37,1,3,IER)                           00000830
      IF(IER.NE.0) OUTPUT(101) IER                                      00000840
      CALL TEXTO(IDEV, NULL, 1,24,43,2,3,IER)                           00000850
      IF(IER.NE.0) OUTPUT(101) IER                                      00000860
      CALL TEXTO(IDEV, NULL, 1,27,29,2,3,IER)                           00000870
      IF(IER.NE.0) OUTPUT(101) IER                                      00000880
      CALL TEXTO(IDEV, NULL, 1,29,31,1,3,IER)                           00000890
      IF(IER.NE.0) OUTPUT(101) IER                                      00000900
      CALL TEXTO(IDEV, NULL, 1,30,33,1,3,IER)                           00000910
      IF(IER.NE.0) OUTPUT(101) IER                                      00000920
      CALL TEXTO(IDEV, NULL, 1,33,30,1,3,IER)                           00000930
      IF(IER.NE.0) OUTPUT(101) IER                                      00000940
```

```
CALL TEXTO(IDEV, NULL, 1,34,33,1,3,IER)                    00000950
IF(IER.NE.0) OUTPUT(101) IER                               00000960
CALL TEXTO(IDEV, NULL, 1,11,27,2,3,IER)                    00000970
IF(IER.NE.0) OUTPUT(101) IER                               00000980
RETURN                                                     00000990
END                                                        00001000
```

```
      SUBROUTINE SPRCTR(ISPRNG,ISEAT, DIFF)                                    00000010
      DIMENSION X(13), Y(13),ISPRNG(13)                                        00000020
      INTEGER YES                                                              00000030
      COMMON AXLTH1, AXLTH2, AXLTH3, AXLTH4                                    00000040
      COMMON WTH1, WTH2, WTH3, WTH4                                            00000050
      COMMON PI, RAD, DEG, IDEV                                                00000060
      COMMON IGDIR(20), ITDIR(40)                                              00000070
      COMMON XA,YA,XB,YB,XC,YC,XD,YD,XE,YE,XF,YF,XG,YG,XH,YH,XS,YS,XP,YP00000080
      COMMON Q1(180),Q2(180),Q3(180),Q4(180),Q5(180),Q6(180),Q7(180)           00000090
      COMMON Q8(180),Q9(180),OMEGA(180)                                        00000100
      COMMON XCAM , YCAM                                                       00000110
      DATA YES/4HYES /, NO/4HNO  /                                             00000120
      NAMELIST IER                                                             00000130
      GDTOCM(A) = 0.2000*A - 1.0000                                            00000140
      ISPRNG(1)  = IHEAD(0,10)                                                 00000150
      X(1)=Y(1) =0.0                                                           00000160
      X(2) = XC  ; Y(2) = YC -.3                                               00000170
      X(3) = XC  ; Y(3) = YC +.3                                               00000180
      DO 100 I = 1, 7                                                          00000190
      Y(3+I) = Y(2+I) - .1                                                     00000200
      X(I+3) = X(I+2) - .1*(-1.0)**(I+2)                                       00000210
  100 CONTINUE                                                                 00000220
      DO 175 I = 1,10                                                          00000230
      X(I) = GDTOCM( X(I) )  ;  Y(I) = GDTOCM( Y(I) )                          00000240
  175 CONTINUE                                                                 00000250
      DO  200 I = 2,10                                                         00000260
      IF(I .EQ. 2) ISPRNG(I) = IPACK( X(I), Y(I), 0);  GO TO 200               00000270
      ISPRNG(I) = IPACK( X(I), Y(I), 1 )                                       00000280
  200 CONTINUE                                                                 00000290
      DO 250 I = 5,9,2                                                         00000300
      ISPRNG(I) = IPACK( X(I), Y(I), 0 )                                       00000310
  250 CONTINUE                                                                 00000320
      ISPRNG(11) = 0                                                           00000330
      CALL GRAPHO(IDEV, ISPRNG, 11,3, IER)                                     00000340
     .IF(IER.NE.0) OUTPUT(101) IER,'SPRCTR'                                    00000350
      IF( ISEAT .EQ. NO)  DIFF = 1.2                                           00000360
      K = 0                                                                    00000370
      SIGN = +1.0                                                              00000380
      X(12) = XS                                                               00000390
      Y(2) = YH - WTH4/2.0 - AXLTH4 + DIFF + YP                                00000400
      Y(3) = Y(2) - 0.4                                                        00000410
      Y(4) = Y(2)                                                              00000420
      DO  275  I = 4,10,2                                                      00000430
      Y(I+1) = Y(I+2) = Y(I) - .1                                              00000440
  275 CONTINUE                                                                 00000450
  300 K = K + 1                                                                00000460
```

```
      DO  350  I = 1,7,2                                                00000470
      X(12-I) = X(13-I) + SIGN*0.3                                      00000480
      X(11-I) = X(12-I) + SIGN*0.1                                      00000490
  350 CONTINUE                                                          00000500
      X(3) = X(11)                                                      00000510
      X(2) = X(4) + 0.3*SIGN                                            00000520
      X(13) = Y(13) = 0.5                                               00000530
      DO  375  I = 1,13                                                 00000540
      X(I) = GDTOCM( X(I) )                                             00000550
      IF( K .EQ. 1 )  Y(I) = GDTOCM( Y(I) )                             00000560
  375 CONTINUE                                                          00000570
      ISPRNG(2) = IPACK( X(2), Y(2), 0 )                                00000580
      ISPRNG(3) = IPACK( X(3), Y(3), 1 )                                00000590
      ISPRNG(4) = IPACK( X(4), Y(4), 0 )                                00000600
      ISPRNG(5) = IPACK( X(2), Y(2), 1 )                                00000610
      DO  400  I = 6, 12, 2                                             00000620
      ISPRNG(I) = IPACK( X(I-1), Y(I-1), 0 )                            00000630
      ISPRNG(I+1) = IPACK( X(I), Y(I), 1 )                              00000640
  400 CONTINUE                                                          00000650
      ISPRNG(13) = 0                                                    00000660
      CALL GRAPHO(IDEV, ISPRNG, 13,10+K, IER)                           00000670
     X IF(IER.NE.0) OUTPUT(101) IER                                     00000680
      X(12) = XP                                                        00000690
      SIGN = -1.0                                                       00000700
      IF( K .EQ. 1 ) GO TO 300                                          00000710
      RETURN                                                            00000720
  500 DO  600  I = 2, 13                                                00000730
      ISPRNG(I) = 0                                                     00000740
  600 CONTINUE                                                          00000750
      CALL GRAPHO(IDEV, ISPRNG, 13,11,IER)                              00000760
     X IF(IER.NE.0) OUTPUT(101) IER                                     00000770
      CALL GRAPHO(IDEV, ISPRNG, 13,12,IER)                              00000780
     X IF(IER.NE.0) OUTPUT(101) IER                                     00000790
      RETURN                                                            00000800
      END                                                               00000810
```

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STRACT

The classical approach for the analysis of linkages has been to assume igid elements during operation. As the operational speeds of mechanisms ncrease, this assumption creates larger errors in the analysis. Thus a etter model of a machine that considers elastic deformations will aid in ore efficient design as well as provide improved accuracy and performance.

This thesis presents a simulation for the dynamic response of an elastic ink model with three clearances. The simulation has been developed for an utomobile, cam actuated valve train. The computer program is coded in ORTRAN IV, for an IBM-360 computer and is included as a portion of this ork. The capability to visually observe the dynamic action of the model is included by a graphic display routine. This routine is implemented in SDS FORTRAN IV for a SDS-9300 computer interfaced with an ADAGE Graphics Display Terminal, Model 10.

Sample problems for various cam speeds of interest are included utilizing graphs and photos from the graphic display.

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
lastic Mechanism						
am Actuated Valve Train						
omputer Graphics						
learance						
ynamic Modeling						
omputer Simulation						

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c.1 The modeling and analysis of an elastic mechanism with clearances.

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